# Appraising Physical Status: The Selection of Measurements

C. H. McCloy

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# APPRAISING PHYSICAL STATUS
# THE SELECTION OF MEASUREMENTS

by

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# ACKNOWLEDGMENTS

This volume represents a compilation of studies which have been carried on by a large number of the staff of the Iowa Child Welfare Research Station. Owing to the interlocking nature of many of these studies, and to the fact that frequently several staff members have coöperated in carrying out a study, it is, in general, impossible to assign credit to any individual for work done. Where this has been possible, acknowledgment is made in the text or in a footnote. Individuals whose studies have contributed to this volume are, in alphabetical order: Bernice Boynton, June Constantine, Abraham Kantrow, Harriet Kelly, Helen Garside Kelly, Virginia Bergstresser Knott, Everett Marshall, C. H. McCloy, Howard Meredith, Eleanor Metheny, S. Idell Pyle, Rosemary Royce, Mabel H. Thurlwell, and Mary Toof. The results have been assembled and the discussion written by C. H. McCloy.

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# FOREWORD

The present study by Professor McCloy and his associates is devoted to an analysis and evaluation of measurements appropriate for the physical appraisal of the child. The argument is that in estimating health such appraisal is coördinate with the more commonly employed practices of family history, physician's examination and laboratory analysis.

There is presented in the monograph a critique of the principal measures available for determinations of weight, fat, limb girths and breathing capacity. In recommending procedures, the author keeps in mind the practical demands of the school or clinic situation. Thus the prediction of optimum weight is based upon simple measures of height, weight, chest circumference, width of hips and width of knee. Standard landmarks, instruments and techniques of measurement are described and illustrated.

George D. Stoddard

Office of the Director
Iowa Child Welfare Research Station
University of Iowa
March 14, 1936

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## CHAPTER I

# THE SELECTION OF ANTHROPOMETRIC MEASUREMENTS FOR THE PURPOSE OF EVALUATING PHYSICAL STATUS

The White House Conference (1932) on Child Health and Protection has focused the attention of the country on the great advances that have been made during the last half century in the methodology of health service and protection. The era when society assumed no responsibility for the physical and mental health of the child, but left it all to the parents and, perchance, to the family physician, has passed forever from the United States. It is true that society does not fully accept this responsibility in every community, but when it fails to do so, it does so apologetically.

In the total picture of the health supervision, health service, and health instruction of our citizens, young and old, there is one element which is essential for the most adequate service to the individual, and that is the accurate appraisement of his present physical and health status.

There are at least four methods of appraising the health of the child, each of which contributes certain specific informations, but no one of which is an entirely adequate record of the child's physical condition.

The first of these methods is to study the history of the child and his immediate ancestors in so far as this applies to health. This concerns itself with the health conditions and length of life of the parents, grandparents, and others close to the child's direct line of descent. This is one of the methods commonly used by physicians and is of help in the total appraisement of the child's probable health condition, but, taken by itself, is apt to be extremely misleading. It is above all a record of the past, and all happenings of the child's past, both in his own life and in the lives of his ancestors, were compounded of hereditary and environmental factors, and we can never be quite sure which of these elements predominated at any given time. The child may have escaped from some of the environmental ruts of his forefathers, and other influences may have entered in. Hence, this method of health appraisement, while of value, cannot be relied upon entirely.

The second method is that of a physician's physical diagnosis. (In this discussion the "physical diagnosis" is assumed to be that part of the medical examination which does not utilize laboratory tests.) In this kind of appraisement the physician examines the various important organs of the body as best he can, interprets his findings in the light of his experiences, and comes to a reasoned-out conclusion. This type of examination is chiefly a search for departures from the "normal." It is not apt in distinguishing between various gradations of health, for with the healthy child the findings are likely to be marked "negative." It states merely that the child, in so far as the examiner can tell, *is not sick*.

The third method of examination utilizes such measurements as blood pressure, the analysis of the body secretions, the analysis of the body excretions, blood count, haemoglobin, basal metabolism, and the X-ray. The addition of these methods of clinical or laboratory diagnosis achieves greater accuracy and throws less strain upon the subjective judgments of the examiners. These methods of measurement are increasing in number and completeness year by year, but there are still great gaps between the need and the accomplishment.

All of the methods presented above are important. All three are used by the competent physician. The first, and, more frequently, the second are often used in routine medical examinations in the schools.

The fourth method of appraisement, that of anthropometric measurements, which is not yet as commonly used as the other three, supplements the information given by them. This method utilizes the physical measurement of the body structures. It will increasingly overlap the laboratory diagnosis method as medical measurements become more quantitative and objective.

By the term anthropometric measurements is meant the objective measurement of certain structures and functions of the body. Measurement of structures includes the measurement of total height, width of shoulders, chest, hips, and knee, depth of chest, and such measures of bulk as weight. By measurement of function is meant such measurements as the frequency of the pulse rate and the arterial and venous blood pressure. Some measurements, such as that of the breathing capacity of the lungs, are on the border line between measurements of structure and measurements of function.

All of these measurements are, in the main, purely objective. There are some small subjective elements encountered, such as individual differences between measurers in the amount of pressure exerted through the instrument, differences of standards in such measurements as the diastolic blood pressure, the response of the subject in such items as the posture assumed while being measured, and the emotional responses which sometimes influence the cardiovascular phenomena.

There are numerous factors, such as differing natural immunities to specific diseases, or the hereditary differences in the quality of the organs, which have perhaps even greater influence on the health and physical condition of the individual, which at the present time are not subject to accurate objective measurement. The nearest approach to securing information concerning these variables, at least in the usual routine of school examinations and the examination in the office of the family physician, is that afforded by the personal and family history of the subject. The story told by the anthropometric measurements is that of present status as to nutritional and developmental condition, respiratory functioning, relative basal metabolism, etc., but there is the possibility of large variations in individual susceptibilities to specific diseases which may alter the picture in any given person. The medical examination is, of course, subject to the same limitations.

The medical examination, as usually conducted, states that certain diseased conditions are or are not present; but it does not state, except as the physician may deduce from shrewd observation based on experience, what the quantitative condition of health may be. The anthropometric appraisement of the physical status offers a fair approximation to a measurement of the present health status of the individual, but, like the medical appraisement, it is not complete and it must be used with due regard for its limitations. It is much better adapted to detecting conditions that are the results of health changes over a considerable period of time than it is to detecting day by day fluctuations, such as might be produced by sudden and acute, but mild, diseases. This is an asset, however, as the importance of long time changes is much greater to the school than is the detection of minor fluctuations. Where the medical examination is available, it should be used, but purely negative findings in this examination — particularly where such examinations are conducted as rapidly and superficially as is frequently done in the public schools — should not be permitted to lead to the assumption that the child is perfectly healthy.

The anthropometric examination may, and frequently does, uncover conditions fully as important as some of the positive medical findings. We refer to conditions of relative malnutrition, poorly developed or relatively diminishing breathing capacity, high basal metabolic rate, and generally poor condition. The anthropometric examination will frequently suggest incipient physical disorders that are not sufficiently advanced to be detected as specific pathologies by the physician. Anthropometric measurement for the appraisement of physical condition is an aid and a supplement to, but in no way a substitute for, the medical examination. It can be applied by trained persons who are not physicians, and it will guide the health administrator to an appropriate medical follow-up of the conditions found.

This series will report such studies as bear upon this general plan for the evaluation of physical status, and present certain standards evolved from those studies. This first volume will be confined to studies concerned with the selection of the best anthropometric measurements for this purpose. Students of physical anthropology have proposed a very large number of measurement techniques and many variations of the individual measurements. It is the task of this volume to assay such of these as apply to the problem of determining physical status and to choose from this number those best adapted, directly or indirectly, to the measurement of physical status with the greatest accuracy and the least administrative difficulty.

The aim of this series of studies is to produce methods that will serve the individual for his welfare. To this end we have made many compromises between complete scientific accuracy and administrative convenience. Experience has demonstrated that anthropometric measurements which are to be used in the schools and in infant clinics, if their use is to be at all widespread, must be such that they can be administered and interpreted by others than the medical profession alone. This is at present primarily a matter of cost. Hence, these measurements will usually be given and interpreted by the school nurse, the teacher of physical education, and others interested in the child's physical welfare whose services can be obtained without extra fee. Therefore, the methods used must be simple enough to be very easily learned and applied. If the computations and tables used consume too much time or are too complicated, regardless of their scientific accuracy, they will not be used extensively. In every case, therefore, we have striven not only for accuracy and adequacy of measurement but for simplicity as well.

In subsequent volumes, standards for the appraisement of physical status, together with tables for their convenient application, will be developed and presented, in addition to other helpful administrative measures.

# CHAPTER II

# INDIVIDUAL DIFFERENCES IN PHYSICAL CONSTITUTION

Early anthropometric standards in most cases were based upon averages of measurements taken on many types and builds of people with nationality, sex, and age constant. This ignored the fact that departures from the average are frequent, and yet are not to be considered as abnormal. On the other hand, at a relatively early date a number of anthropometrists and physicians recognized the fact of individual differences in build and attempted to classify individuals into a small number of categories. These classifications have usually assumed a relatively tall, slender type at one extreme and a relatively shorter but stockier type at the other. In general, an intermediate or "normal" type has been placed in between. Variants of some of these types have been proposed by a few of the authors. In the tabulation on the following page will be found a summary of the most important studies and writings on this problem.

## METHODS FOR CLASSIFYING BODY BUILDS

The methods used for classifying the different body builds may be roughly divided into four general types.

### *Indices of Build*

One type of classification is that which uses definite indices of build based upon index numbers with height as the denominator. The following indices have been proposed:

$$\frac{\text{Weight}^{1/3}}{\text{Height}}\ ;\ \frac{\text{Weight}}{\text{Height}^{3}}\ ;\ \frac{\text{Weight}}{\text{Height}^{2.5}}\ ;\ \frac{\text{Weight}}{\text{Height}^{2}}\ ;\ \text{and}\ \frac{\text{Weight}}{\text{Height}}$$

Indices of this type have been studied at this Station by plotting the mean weight for each height for each sex at each year of age and fitting curves to the results (21, p. 28-34). Kelly found the index of $\frac{\text{Weight}}{\text{Height}^{3}}$ to be the most satisfactory one for males (the actual exponent of Height was 3.042), and $\frac{\text{Weight}}{\text{Height}^{2.79}}$ to be the

| AUTHORITY | CLASSIFICATIONS OF BODY BUILD** | | | |
|---|---|---|---|---|
| | I | Ia | II | III |
| Hippocrates | Habitus phthisicus | | Habitus apoplecticus | |
| Halle, 1797 (30)* | Chest type | Head type or nervous type | Athletic type or muscular type | Stomach type |
| Thomas, 1821 (30)* | Chest type | Skull type | | Stomach type |
| Rostan, 1826 (30)* | Respiratory type | Cerebral type | Muscular type | Digestive type |
| Walker, 1852 (30)* | | Mental type | Exercise type | Digestive type |
| Carus, 1853 (9) | Asthenic type | | Athletic type | Phlegmatic type |
| DeGiovanni, 1877 (30)* | Phthistic type | | Plethoric type | |
| Virenius, 1904 (30)* | Epitheliar type | Nervous type | Muscular type | Mesotheliar type |
| Sigaud, 1904 (40) | Respiratory Type | Cerebral type | Muscular type | Digestive type |
| Bryant, 1913 (7) | Carnivorous type | | Normal type | Herbivorous type |
| Goldthwait (18) | Carnivorous type | | Normal type | Herbivorous type |
| Kretschmer (23) | Asthenic type | | Athletic type | Pyknic type |
| Manouvrier (28) | Macroscelous type | | Mesatoscelous type | Brachyscelous type |
| Viola (44) | Microsplanchnic | | Normosplanchnic | Megalosplanchnic |
| Pende (35) | Hypovegetative | | | Hypervegetative |
| Bauer (3) | Asthenic habitus | | Sthenic type | Arthritic habitus |
| Mills (32) | Hyposthenic-asthenic type | | | Hypersthenic type |
| Brugsch (6) | Asthmatic type | | Normal chest | Broad chest |
| Davenport (13) | Lean | | Medium | Fleshy |
| Bean (4) | Hyperontomorph | | | Mesontomorph |
| Stockard (41) | Linear | | Normal | Lateral |
| Aschner (1) | Small | | Normal | Wide |
| Pathological Principles | Asthenic | Infantile | Normal | Apoplectic |

* (p. 231-234)

** All of the terms listed under each column are essentially the same in meaning. For this reason only a few are used in the discussion in this chapter. Type Ia is a variant of I. Where nothing is listed under II, the author does not discuss the intermediate type but only the extremes. Bean (4), in addition to the two types listed here, has still another type, not falling under any of these categories, which he calls the hypo-ontomorph. This is essentially a low thyroid type resembling the body build of the cretin.

most satisfactory for females. $\frac{\text{Weight}}{\text{Height}^3}$ differed very slightly from this curve.

Since weight is a measure of volume and volumes grow according to the cube of the linear dimension, one would expect, *a priori,* what Kelly found to be true, that the best index would be either $\frac{\text{Weight}^{1/3}}{\text{Height}}$ or $\frac{\text{Weight}}{\text{Height}^3}$. When no exponent is used, as in the $\frac{\text{Weight}}{\text{Height}}$ index, the average index increases greatly as the height increases, for the weight increases proportionately much faster than does the height. Within the same physiological age group, this is not true when both weight and height are reduced to the same power.

In studying distributions of these indices, it was found that the $\frac{\text{Weight}^{1/3}}{\text{Height}}$ index gives a more normal (and less skewed) distribution than does the $\frac{\text{Weight}}{\text{Height}^3}$. It possesses the additional advantage of being very much more quickly and accurately computed on a slide rule than is the $\frac{\text{Weight}}{\text{Height}^3}$ index. Hence, we propose it as the most desirable of this group.

In the same category of index numbers we find three others proposed: (1) $\frac{\text{Weight}}{\text{Sitting Height}^3}$ (Von Pirquet) was proposed rather arbitrarily and has in general been rejected by the anthropologists who have studied it. (2) $\frac{\text{Sitting Height}}{\text{Height}}$ assumes that in the stockier type the legs will be much shorter and in the linear type the legs will be much longer. (3) $\frac{\text{Chest Circumference}}{\text{Height}}$ assumes that stockiness and a relatively large chest are very closely related. The $\frac{\text{Chest Circumference}}{\text{Height}}$ index gives essentially the same information as does the weight index. In two groups of young adults the chest circumference (corrected for fat) correlated against the $\frac{\text{Normal Weight}^{1/3}}{\text{Height}}$ index gave a correlation coefficient of .89 for males and .80 for females. $\frac{\text{Sitting Height}}{\text{Height}}$ when correlated against $\frac{\text{Weight}^{1/3}}{\text{Height}}$ gave a correlation of only .21 for males, while $\frac{\text{Sitting Height}}{\text{Height}}$ when correlated with $\frac{\text{Chest Circumference}}{\text{Height}}$ gave only .20. Apparently $\frac{\text{Chest Circumference}}{\text{Height}}$ and the weight index agree reasonably well. The other is not consistent with the weight index or with the chest circumference index, and if it is of value, it is for some other purpose.

The advantage of this index type of determiner of build is that it makes no attempt to develop arbitrary and separate categories, but assumes a continuous distribution from one end of the group to the other.

### *Subjective Determination of Categories*

A second type of classification of build is one which attempts subjectively to place all individuals into two, three, or more clear-cut categories. The classification of Hippocrates, dividing individuals into two general groups, the *habitus phthisticus* and the *habitus apoplecticus,* was the first of these to be proposed. A number of other recent proposals which summarize the best of the older ones is seen in the classifications of Bryant (7) and of Goldthwait (18), who propose a three category classification of carnivorous (linear), normal, and herbivorous (stocky) types; and of Stockard (41), who uses the same classification, but calls them linear, intermediate, and lateral. The authors classify individuals as to these types by inspection alone.

### *Kretschmer's Classification*

A third method is seen in the classification by Kretschmer (23, p. 20-34) in which he proposes a linear type which he calls the asthenic and a stockier lateral type which he calls the pyknic, with mixed or intermediate types. In addition he adds a third true type which he calls the athletic type, which is a deviate, according to his description, from the series, running between the asthenic and pyknic. In the light of the prominence Kretschmer's writings have assumed in the literature, this classification will be discussed in more detail below.

### *Draper's Classification*

A further system of classification is that of Draper (14), who classified his people into finer groups, not according to some preconceived scheme, but according to the general proportions of those whom he finds to be particularly predisposed to certain diseases. His tubercular type and his gastric ulcer type are both slender or linear types. His gall bladder type and his pernicious anemia type are both laterals or stockier builds. These individual types, however, deviate also in shape of face and proportions of various parts of the face and body. It will be seen that in spite of this attempt at a finer classification, the slender groups fall together and the stocky groups fall together. Draper's classification, however, is not intended as a systematical grouping of individuals anthropologically, but is for the purpose of selecting those who are most apt to be susceptible to given disease entities. This falls outside the scope of this volume, so we shall not consider it further.

## GENERAL CONSIDERATIONS

The measurement of physical constitution or body type is important in all studies in which physical status is assessed from anthropometric measurements. It is obvious that the same standard for the determination of under- and overweight or muscle development cannot be used for the slender and for the stocky type. It is evident that a dray horse and a race horse may be of the same height and of the same length, but it would be absurd to assume that they both should weigh the same amount. It is therefore important in applying anthropometric techniques to the determination of physical status (a) to know whether there are several distinct body types, or simply a distribution of builds, reaching from one extreme to the other, with certain features varying somewhat from the average for that part of the distribution, and (b) when this first question has been answered, to establish a method of distinguishing accurately the type or the point on the range of the distribution of build.

As has been pointed out by Montessori (33, p. 67-106), the stocky or lateral type has a larger amount of digestive organs per unit of body volume than does the linear or slender type. This type of individual, therefore, has comparatively more area from which to absorb food than does the linear type, and it has been stated (7, 33, 41) that this type of individual tends to put on weight and to be much better nourished than the linear type, who tends toward malnourishment. As a result of chronic overnourishment, in sedentary life the stocky type is assumed to place a greater burden upon the kidneys and the circulatory system and to suffer more from diseases of these organs, while the linear type tends to suffer more from diseases of the lungs and digestive organs and other types of diseases which are associated with poor nutrition. These assertions are upheld by evidence from insurance statistics, one sample of which is shown in the following tabulation:

Relationship of Bodily Habitus to Disease
According to the Life Insurance Records

| Cause of Death | Thin | Physique<br>Medium<br>Per Cent | Stout |
|---|---|---|---|
| Tuberculosis | 25.7 | 13.1 | 4.1 |
| Apoplexy | 4.9 | 9.2 | 12.3 |
| Circulatory Disturbances | 9.4 | 14.8 | 22.7 |
| Pneumonia | 11.7 | 10.3 | 7.7 |
| Malignant Tumors | 6.4 | 8.3 | 7.1 |
| Infectious Disorders | 5.4 | 4.6 | 4.1 |
| Brain Disorders | 10.6 | 9.8 | 6.6 |
| Suicide | 4.7 | 5.1 | 4.1 |
| Various other diseases | 21.1 | 24.8 | 30.5 |
| Total | 100.0 | 100.0 | 100.0 |

Further evidence to this effect is given in Davenport's (13) study on *Body Build and Its Inheritance.*

In line with the above considerations, we have also the fact that the linear type in general has a larger musculature proportionate to his vegetative or visceral parts. He has longer limbs and a smaller trunk, which gives him relatively more muscular tissue to nourish and to supply with oxygen than is the case of the stockier lateral. Montessori (33) has referred to the linear as the type of individual with a small boiler and a relatively large engine, while the lateral is an individual with a larger boiler but a smaller engine. Draper's studies (14) seem to indicate that the problem is considerably more complex than it has been made to appear.

These considerations are listed here primarily to convey the idea that there is much more to the problem of body type than simply differences in physical proportions.

## QUESTIONS CONSIDERED IN THIS STUDY

From the standpoint of the problems raised in this volume, it is not necessary for us to discuss the relationships of body build to disease. While this is an important consideration for the physician and perhaps for the hygienist, it is not necessary to consider these problems in a study in which the major emphasis is the selection of anthropometric measurements for the purpose of evaluating present physical status. The principal questions concerning body build to be considered in this volume are the following:

1. Are there several distinct categories of body build, as is suggested by Kretschmer (23), or is there a continuous distribution from one extreme to the other, with perhaps a number of atypical deviates from the general trend?

2. What are the simplest and best methods of indicating the body build or type of any given individual?

3. How can the methods of determining body type best be utilized in the appraisement of physical status?

In the writings on body build cited or discussed above, all but those of Kretschmer (23) and Draper (14) either indicate or imply that there is a continuous distribution from one extreme to the other, though a number of them imply that usually it is relatively easy to place an individual subjectively in one of the extreme categories or in the middle. In some instances where indices are given (such as $\frac{\text{Weight}^{1/3}}{\text{Height}}$, etc.), these "types" are given by arbitrarily dividing the range into three groups (33, p. 67-106). From the standpoint of modern anthropometry, there is no reason why such a continuous distribution might not better be described in terms of deviations from the average, with the deviations stated in terms of some statistical constant such as the standard deviation.

Kretschmer and his disciples, on the other hand, imply three distinct distributions with relatively little overlapping. The first of these, the asthenic type, is conceived of as a slender, small muscled, fairly tall, and long limbed individual. The other extreme, the pyknic type, is thought of as a stocky, short limbed, large trunked person. The third type suggested, the athletic type, according to Kretschmer, is not an intermediate type but a deviate from the intermediate type showing certain distinct characteristics. When the data are analyzed, the major differentiation seems to be that this type is distinguished from an intermediate type by slightly wider shoulders.

A number of Kretschmer's students have attempted to prove this point with indices and have developed a number of anthropometric methods for arbitrarily dividing one type from the other.

The most important of these indices are listed in the following tabulation:

1. Pignet's Index

$$\text{Height} - (\text{Chest Circumference} + \text{Weight})$$

2. Chest-Shoulder Index

$$\frac{\text{Shoulder Breadth} \times 100}{\text{Chest Circumference}}$$

3. "Index A"

$$\frac{\text{Head Height} \times \text{Hand Circumference} \times \text{Shoulder Breadth} \times \text{Chest Circumference}}{1000}$$

4. "Index B"

$$\frac{\text{Height} \times 10{,}000}{\text{Chest Breadth} \times \text{Chest Depth} \times \text{Anterior Trunk Length} \times \text{Shoulder Breadth}}$$

5. "Index C"

$$\frac{\text{Chest Breadth} \times \text{Chest Depth} \times \text{Shoulder Breadth}}{\text{Bi-iliac} \times \text{Bi-trochanteric}}$$

6. "Index D"

$$\frac{\text{Shoulder Breadth} \times \text{Hand Circumference} \times \text{Arm Length} \times \text{Leg Length}}{\text{Chest Circumference} \times \text{Abdomen Circumference} \times 100}$$

7. Wertheimer's Index

$$\frac{\text{Leg Length} \times 10^5}{\text{Chest Breadth} \times \text{Chest Depth} \times \text{Trunk Length}}$$

8. Andreew's Index

$$\frac{100\,[(\text{Chest Circumference} + \text{Abdomen Circumference}) - (\text{Arm Length} + \text{Leg Length})]}{\text{Chest Breadth} \times \text{Chest Depth}}$$

A fairly large proportion of these are obviously invalid from a purely mathematical point of view. The number of anthropometric measurements multiplied together in the numerator is different from the number in the denominator. For example, in Index B, height is the only measurement in the numerator, while the denominator is composed of the product of four linear measurements. Wertheimer's index has a similar defect. In Index C and Index D the numerator is composed of the product of three measurements and the denominator of two. In Andreew's Index, the numerator is composed of a series of sums and differences while the denominator is a product of two linear measurements. Index A has as its numerator the product of four dimensions with a constant in the denominator. It will be seen from these facts that the actual body size of individuals will determine the size of the index; for example, in Index B, the larger the person, the smaller the index will be; in Index A, the larger the person, the larger the index will be. Since the pyknic type of individual and the athletic and asthenic type of individual differ in pure size as well as in build, there will be a tendency, in adults at least, for these indices to classify on the basis of total bulk alone as much as on the basis of actual type.

A series of distributions is given (24, 45, 46, 47) in which these indices distinguish the types rather readily. A number of these indices, used on the original data, apparently divide the three types with a fair degree of satisfaction, though in almost all there is a rather large degree of overlapping. When the indices are corrected by converting the numerator and the denominator into terms of the same power, this ability to differentiate between types is lessened, and the differences are largely those that would be expected from differences in the relative stockiness of the body.

Further, when these distributions, even in their original form, are combined into one distribution, in almost every case they form a continuous unimodal curve which is usually quite symmetrical. (See Figure 1). This fact, together with the fact that there is so much overlapping in the distribution of the individual types, would seem to indicate that these indices of type do not sharply differentiate between any three given, arbitrary body builds, but that the individual's build may be best indicated by its position in a total distribution.

In evaluating these studies of index numbers made by the Kretschmer school, one should also make note of the fact that the cases selected by no means represent a random sample of the population, but rather represent specific groups of individuals chosen because they were as nearly pure types as it was possible to secure. Usually this group makes up less than half of a random sample. If it is impossible to separate these carefully chosen individuals sharply on the basis of such index numbers, it would seem probable that these three types do not really exist as separate entities. Still further evidence is shown as one studies the average measurements of these three types converted into obtained indices by dividing each measurement by the average height for the group. Two such samples are presented in Tables 1 and 2.

It will be noted in studying these indices that in almost every case in measurements of length the athletic type is either very similar to the asthenic or is intermediate between the asthenic and the pyknic type. In measurements of circumference, thickness, and width, in every case the athletic type is intermediate between the asthenic and the pyknic. The one measurement in which this is

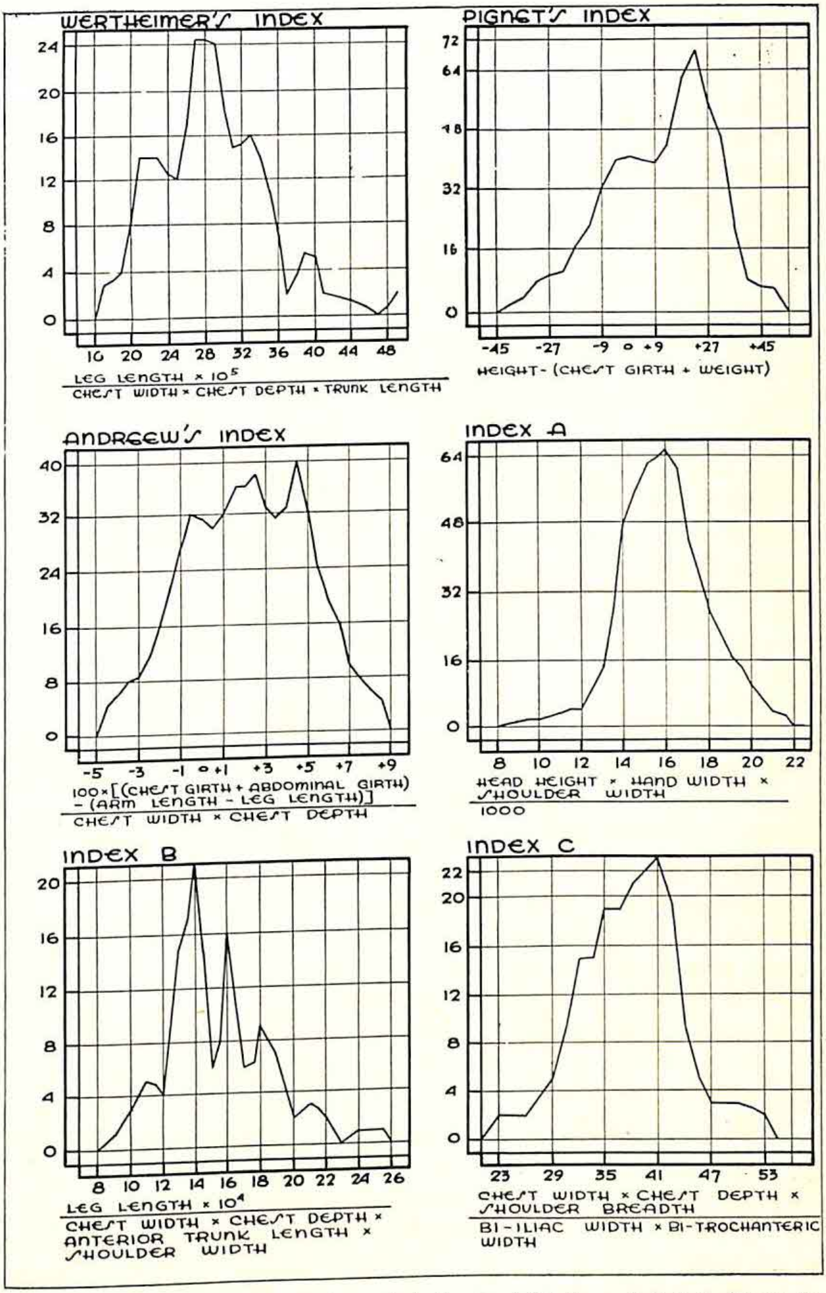

Figure 1. Combined Distributions of Asthenic, Athletic, and Pyknic Types for Various Indices of Build

not true is width of shoulders. Studies made in this Station indicate that the width of shoulders of the athletic group is approximately one standard deviation of such an index wider than the shoulders of the asthenic group. Since the width of the shoulders is the outstanding physical trait used by the Kretschmer school to place individuals in the athletic class, this is probably not a true type difference, but simply a result of using this trait as a classifier. Certainly one would expect to find the difference greater than one standard deviation if it were a true distinguishing characteristic.

The fact that in lengths, such as arm length and leg length, the athletic type resembles most the asthenic type, together with the fact that in all of the measurements of bulk this type is intermediate, would lead us to conclude that the athletic type is simply a variant of the asthenic type in that it represents a number of individuals who are nearer the average of the total distribution and who are somewhat better developed.

This latter statement concerning the relative development of the

Table 1

Average Measurements of Individuals of Different Types
Both Actual and Relative*

| Measurement | Asthenic | | Athletic | | Pyknic | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female |
| | | | Averages | | | |
| Height | 168.4 | 153.8 | 170.0 | 163.1 | 167.8 | 156.5 |
| Weight | 50.5 | 44.4 | 62.9 | 61.7 | 68.0 | 56.3 |
| Shoulder Width | 35.5 | 32.8 | 39.1 | 37.4 | 36.9 | 34.3 |
| Chest Girth | 84.1 | 77.7 | 91.7 | 86.0 | 94.5 | 86.0 |
| "Stomach" | 74.1 | 67.7 | 79.6 | 75.1 | 88.8 | 78.7 |
| Calf Girth | 30.0 | 27.7 | 33.1 | 31.7 | 33.2 | 31.2 |
| Leg Length | 89.4 | 79.2 | 90.9 | 85.0 | 87.4 | 80.5 |
| | | | 100 x Averages Divided by Height | | | |
| Weight $\left(\frac{\text{Weight}^{1/3}}{\text{Height}}\right)$ | 22.0 | 23.0 | 23.4 | 24.2 | 24.4 | 24.5 |
| Shoulder Width | 21.1 | 21.3 | 23.0 | 22.9 | 22.0 | 21.9 |
| Chest Girth | 50.0 | 50.5 | 53.9 | 52.8 | 56.2 | 55.0 |
| "Stomach" | 44.0 | 44.0 | 46.8 | 46.0 | 52.9 | 50.2 |
| Calf Girth | 17.8 | 18.0 | 19.4 | 19.4 | 19.8 | 19.9 |
| Leg Length | 53.2 | 51.5 | 53.4 | 52.1 | 52.1 | 51.4 |

* From Kretschmer (23)

Table 2
Average Measurements of Women of Different Types
Both Actual and Relative*

| Measurement | Actual Averages | | | Averages Divided by Height | | |
|---|---|---|---|---|---|---|
| | Asthenic | Athletic | Pyknic | Asthenic | Athletic | Pyknic |
| Head Height | 19.1 | 17.84 | 20.36 | 12.2 | 12.0 | 12.3 |
| Leg Length | 82.6 | 77.16 | 88.04 | 51.3 | 51.7 | 51.2 |
| Height | 159.5 | 149.00 | 170.00 | | | |
| Weight | 68.9 | 56.17 | 83.42 | 25.7 | 25.7 | 26.2 |
| Shoulder Breadth | 36.1 | 33.72 | 38.48 | 21.5 | 22.6 | 22.0 |
| Chest Circumference | 83.7 | 78.19 | 89.21 | 50.2 | 52.4 | 56.0 |
| Abdomen Circumference | 74.1 | 69.22 | 78.98 | 42.8 | 46.4 | 51.0 |
| Hand Circumference | 18.9 | 17.66 | 20.14 | 11.4 | 11.8 | 11.9 |
| Chest Depth | 17.9 | 16.72 | 19.08 | 10.9 | 11.2 | 12.6 |
| Chest Width | 25.2 | 23.54 | 26.86 | 15.5 | 15.8 | 16.7 |
| Anterior Trunk Length | 47.4 | 44.28 | 50.52 | 30.0 | 29.7 | 29.6 |
| Arm Length | 68.2 | 63.70 | 72.69 | 43.1 | 42.7 | 41.9 |
| Bi-Cristal Hip Width | 28.6 | 26.72 | 30.48 | 18.0 | 17.9 | 19.6 |
| Bi-Trochanteric Hip Width | 33.0 | 30.83 | 35.17 | 20.2 | 20.7 | 22.1 |

* From Kühnel (24)

athletic type is borne out in Kühnel's paper (24) in which he naïvely remarked that it was possible to fill out his numbers of athletic women only by recourse to the school for training women teachers of physical education. To these were added some individuals from two hospitals. Since these individuals were presumably physically well, they probably represent nurses, though this is not stated.

We reject, therefore, the Kretschmerian method of subjectively classifying individuals into distinct arbitrary types for the more objective one of selecting relatively simple measurements which will best distinguish the place in a distribution of the population occupied by the individual.

The problem then resolves itself into an attempt to determine what indices, composed of which measurements, are best adapted to differentiate the types.

## A FACTOR ANALYSIS APPROACH

The approach to the problem of determining which measurements are best adapted to identifying body types has been made by the use of the recently developed technique of factor analysis. Since we have used the method proposed by Thurstone (42), we shall confine our statements to this method, instead of discussing other methods which have been devised for the same purpose.

The method of factor analysis is one which, when used upon material which may be logically assumed to be amenable to analysis by this technique, causes components which are common to all or various groups of variables to emerge and to become subject to quantitative treatment. When the mathematical processes are completed, so-called factor loadings are obtained for each of these factors or components which are in effect zero order correlations of each variable with these factors. The method itself contributes nothing to the identification of these factors or components. Such identification must be made upon other grounds. Usually, however, the logic of the situation is sufficiently clear to render such identification relatively easy.

In this study, eighteen anthropometric measurements were analyzed by the method of factor analysis for each of six age groups of each sex. The measurements and age groupings will be seen in Tables 3 to 8. Three important common growth factors emerged and were identified with relative ease. The first factor is evidently that which represents the linear growth component and is greatest in such measurements as height and sitting height. A second factor has been called the factor of cross-sectional growth. This factor is zero, or approximately so, in height and sitting height, and is most heavily loaded in such measurements as the chest dimensions and the girths of the limbs. A third factor, fat, is very little larger than its probable error in anything except the four measurements of fat.

As we examine these tables, it is apparent, as would be expected, that height is by all odds the best measurement of linear growth. Since body build seems to be primarily a relationship of cross-sectional growth to linear growth, we must determine the best measurement of the cross-sectional growth component. The largest correlation between the cross-sectional growth factor and the individual measurements is found in the muscle girths. These, however, are not satisfactory measurements for the purpose of identifying types because of their great propensity to changes, both in fat distribution and muscular development. To illustrate, it would be quite possible if the girth of the upper arm were used for the purpose of determining build to change an individual from the linear to the lateral end of a distribution after a year of heavy gymnastics, or for an individual having the misfortune to become emaciated because of some disease to change from lateral to linear within a season. It is therefore desirable that the measurement used should be one not of muscular development but of bony framework. From the standpoint of the factor analysis, the best choice seems to be that of chest circumference. Additional evidence to support this choice is also found on page 48.

Consideration was next given to weight as a possible better measure of cross-sectional growth. Since weight is composed largely of linear growth as well as of cross-sectional growth, linear growth was partialed out. Since the correlation between orthagonal factors is zero, the partial correlation of weight and cross-sectional growth, with linear growth constant, could well be com-

Table 3
Factor Loadings for Fat Growth: Males

| Measurement | Age Group | | | | | |
|---|---|---|---|---|---|---|
| | Babies | 4 Years | 6 Years | 10 Years | 14 Years | College |
| Weight | −.0100 | −.0067 | .0489 | .1202 | .0002 | .043 |
| Height | .0808 | .0279 | .0043 | .1403 | .0398 | .128 |
| Sitting Height | .0531 | .0135 | −.0078 | .0752 | .0178 | .086 |
| Shoulders | −.0530 | −.1509 | .0257 | −.0424 | −.0204 | −.043 |
| Hips | −.0006 | −.1320 | .1181 | −.0414 | .0621 | .273 |
| Chest Width | | .1068 | −.3182 | −.1907 | .0123 | −.018 |
| Chest Depth | | −.3317 | −.1979 | −.1450 | .0378 | .030 |
| Chest Circumference | −.0076 | .0619 | −.0929 | −.0945 | −.0349 | −.010 |
| Elbow | −.1816 | −.1641 | −.0622 | −.1698 | −.0034 | .250 |
| Knee | −.2392 | .1793 | −.0061 | −.0633 | .0288 | −.256 |
| Arm | .0877 | .0870 | .1632 | .1263 | −.0004 | .011 |
| Forearm | .0717 | .1029 | .0124 | −.0552 | −.1078 | −.058 |
| Thigh | .0768 | −.0577 | .0868 | .1503 | .0361 | .208 |
| Calf | .0781 | −.1416 | −.0144 | −.0033 | .0032 | −.063 |
| Arm Front | .3207 | .7397 | .6670 | .4255 | .2474 | .544 |
| Arm Back | .4594 | .6061 | .6972 | .5090 | .1801 | .498 |
| Chest Front | .5234 | .8603 | .6835 | .5927 | .2441 | .672 |
| Chest Back | .5685 | .6574 | .5106 | .6281 | .1505 | .538 |

Table 4

Factor Loadings for Cross Sectional Growth: Males

| Measurement | Age Group | | | | | |
|---|---|---|---|---|---|---|
| | Babies | 4 Years | 6 Years | 10 Years | 14 Years | College |
| Weight | .4538 | .5757 | .5762 | .5588 | .3172 | .818 |
| Height | .0000 | .0000 | .0000 | .0000 | .0000 | .000 |
| Sitting Height | .1300 | −.0364 | .1175 | .0819 | −.0304 | .051 |
| Shoulders | .5143 | −.0233 | .2698 | .2719 | .0530 | .363 |
| Hips | .5661 | .3040 | .2151 | .2286 | .1660 | .313 |
| Chest Width | | .2192 | .5489 | .4425 | .2514 | .646 |
| Chest Depth | | .4052 | .5488 | .5975 | .2913 | .667 |
| Chest Circumference | .4759 | .5220 | .7427 | .5944 | .3639 | .838 |
| Elbow | .5122 | .7618 | .2567 | .2885 | .0867 | .375 |
| Knee | .3885 | .5648 | .2199 | .3482 | .3028 | .464 |
| Arm | .6931 | .8255 | .8337 | .7522 | .5800 | .910 |
| Forearm | .7054 | .9111 | .7235 | .7020 | .3356 | .812 |
| Thigh | .6259 | .7849 | .7623 | .7040 | .6349 | .860 |
| Calf | .6824 | .7846 | .6789 | .6349 | .3960 | .705 |
| Arm Front | .5997 | .1674 | .4186 | .6537 | .8435 | .592 |
| Arm back | .6013 | .1857 | .4586 | .6273 | .8065 | .612 |
| Chest front | .4678 | .1661 | .3281 | .6149 | .8314 | .451 |
| Chest back | .4489 | .2470 | .5246 | .4993 | .8007 | .367 |

Table 5

Factor Loadings for Linear Growth: Males

| Measurement | Age Group | | | | | |
|---|---|---|---|---|---|---|
| | Babies | 4 Years | 6 Years | 10 Years | 14 Years | College |
| Weight | .8778 | .7694 | .7749 | .7843 | .9588 | .514 |
| Height | .9239 | .9679 | .9341 | .9557 | .8146 | .842 |
| Sitting Height | .8828 | .8910 | .8413 | .8954 | .7996 | .561 |
| Shoulders | .6387 | .5528 | .6828 | .6172 | .5017 | .414 |
| Hips | .7284 | .6065 | .7339 | .8072 | .6514 | .540 |
| Chest Width | | .6462 | .4456 | .6285 | .7138 | .357 |
| Chest Depth | | .4452 | .3307 | .5312 | .5192 | .176 |
| Chest Circumference | .8175 | .5727 | .5123 | .6946 | .8146 | .217 |
| Elbow | .6537 | .3468 | .6771 | .6886 | .4777 | .458 |
| Knee | .7496 | .5372 | .7835 | .8103 | .5782 | .332 |
| Arm | .6650 | .1682 | .3566 | .5312 | .7721 | .034 |
| Forearm | .6803 | .2513 | .5620 | .6154 | .8238 | .276 |
| Thigh | .6707 | .3220 | .4621 | .6279 | .8445 | .124 |
| Calf | .6912 | .2585 | .5969 | .6723 | .7416 | .152 |
| Arm Front | .5662 | −.1467 | .0815 | .1477 | .7728 | −.188 |
| Arm Back | .5075 | −.1974 | .1418 | .2847 | .7350 | −.230 |
| Chest Front | .5076 | −.2568 | −.0216 | .2356 | .7614 | −.193 |
| Chest Back | .5711 | −.2654 | .0786 | .3918 | .6781 | −.247 |

## Table 6
## Factor Loadings for Fat Growth: Females

| Measurement | Age Group | | | | |
|---|---|---|---|---|---|
| | Babies | 4 Years | 6 Years | 10 Years | 13 Years |
| Weight | .0706 | .0881 | −.0707 | .0015 | .1043 |
| Height | −.1001 | −.0129 | −.0307 | .0258 | .0051 |
| Sitting Height | −.1720 | −.1457 | −.0433 | −.0315 | .0130 |
| Shoulders | −.1824 | −.0189 | .0848 | .0613 | −.1587 |
| Hips | −.1486 | .1842 | .0720 | .0550 | .0737 |
| Chest Width | | −.1986 | −.0407 | .1760 | −.1344 |
| Chest Depth | | −.0834 | −.0595 | .2599 | .1358 |
| Chest Circumference | .0690 | .0860 | .0131 | .2251 | .0313 |
| Elbow | −.1685 | −.2157 | −.1964 | −.2354 | −.2319 |
| Knee | −.2214 | .2031 | .0886 | −.4926 | .0919 |
| Upper Arm | .2000 | .0016 | −.0139 | .1159 | .0764 |
| Forearm | .0489 | −.0377 | .0128 | −.0374 | −.0461 |
| Thigh | .2254 | .1800 | .1162 | .0444 | .1612 |
| Calf | .2821 | −.1645 | −.0043 | −.0786 | .0063 |
| Arm Front | .4590 | .7784 | .6578 | .2359 | .6486 |
| Arm Back | .5795 | .6492 | .5249 | .2535 | .5334 |
| Chest Front | .6921 | .5554 | .7536 | .1019 | .4526 |
| Chest Back | .5323 | .2106 | .6379 | .3955 | .4986 |

## Table 7
## Factor Loadings for Cross Sectional Growth: Females

| Measurement | Age Group | | | | |
|---|---|---|---|---|---|
| | Babies | 4 Years | 6 Years | 10 Years | 13 Years |
| Weight | .2658 | .5611 | .4898 | .6607 | .6787 |
| Height | .0000 | .0000 | .0000 | .0000 | .0000 |
| Sitting Height | .2427 | .1006 | .0670 | .0557 | .0351 |
| Shoulders | .7532 | .2685 | .2716 | .2295 | .4493 |
| Hips | .7231 | .3149 | .1079 | .3718 | .3261 |
| Chest Width | | .5817 | .2513 | .4484 | .5938 |
| Chest Depth | | .7328 | .2619 | .5782 | .6210 |
| Chest Circumference | .4899 | .7994 | .4769 | .6533 | .7062 |
| Elbow | .6768 | .5758 | .3673 | .3654 | .6453 |
| Knee | .6807 | .4455 | .2344 | .4820 | .6082 |
| Upper Arm | .7027 | .8205 | .8164 | .8266 | .8384 |
| Forearm | .6522 | .8481 | .5970 | .8186 | .8289 |
| Thigh | .6465 | .7350 | .5912 | .8069 | .6725 |
| Calf | .6675 | .6616 | .5847 | .6905 | .7385 |
| Arm Front | .4827 | .2768 | .4792 | .8666 | .5148 |
| Arm Back | .4048 | .4640 | .6084 | .8292 | .6743 |
| Chest Front | −.0050 | .4216 | .1728 | .7377 | .3193 |
| Chest Back | .3426 | .4698 | .5509 | .6512 | .4789 |

Table 8
Factor Loadings for Linear Growth: Females

| Measurement | Age Group | | | | |
|---|---|---|---|---|---|
| | Babies | 4 Years | 6 Years | 10 Years | 13 Years |
| Weight | .9511 | .8016 | .8047 | .7126 | .7002 |
| Height | .9146 | .8909 | .8789 | .9112 | .9281 |
| Sitting Height | .8445 | .9182 | .8444 | .8375 | .8562 |
| Shoulders | .1904 | .7070 | .7262 | .6937 | .5343 |
| Hips | .3274 | .7418 | .9037 | .8217 | .8192 |
| Chest Width | | .5343 | .7960 | .6552 | .5789 |
| Chest Depth | | .1485 | .5607 | .4142 | .4472 |
| Chest Circumference | .7255 | .4374 | .7216 | .5622 | .4441 |
| Elbow | .4539 | .4930 | .6425 | .5668 | .3788 |
| Knee | .3706 | .6831 | .8147 | .5880 | .4247 |
| Upper Arm | .5606 | .2023 | .5081 | .3339 | .3815 |
| Forearm | .6357 | .3965 | .6671 | .3981 | .4170 |
| Thigh | .5396 | .4940 | .6248 | .4417 | .5977 |
| Calf | .5828 | .5278 | .7103 | .4758 | .4786 |
| Arm Front | .3518 | −.0084 | .2916 | .0218 | .1414 |
| Arm Back | .3200 | .1390 | .2366 | −.0854 | .2487 |
| Chest Front | .3661 | .1144 | .3783 | .0075 | .2102 |
| Chest Back | .3311 | −.1309 | .2356 | .0407 | .0641 |

puted. For the twelve age groups computed, the partial correlation was above .90 in nine cases, above .80 in two cases, and .735 in the remaining case (ten-year-old boys). These correlations are larger than the factor loadings of the largest other measurement with cross-sectional growth in nearly all cases; hence, when used in the form of $\frac{\text{Weight}^{1/3}}{\text{Height}}$, an index which of itself "holds height (linear growth) constant," this should be a very superior index of body build.

If weight is used in its crude form (actual weight), this index number would be subject to the same objections as those raised to the use of the girth of the limbs, namely, that it might be unduly influenced by fat or muscular development. This objection can be readily obviated, however, by using the predicted normal weight (see Chapter IV) in place of actual weight. As this normal weight is computed from skeletal measurements which have been corrected for fat, this objection is removed.

Since the index of build is expressed in terms of cross-sectional growth relative to linear growth in the case either of chest circumference or $\text{Weight}^{1/3}$, the number indicating cross-sectional growth should be divided by height. Thus we propose for use as indices for the purpose of indicating build either $\frac{\text{Chest Circumference}}{\text{Height}}$ or $\frac{\text{Normal Weight}^{1/3}}{\text{Height}}$. The former is the simpler and the more convenient to use. If normal weight is available, however, the second index can be computed almost as rapidly on a slide rule by the use of the cube scale.

As has been indicated by the researches of Draper (14), it is probably true that to divide constitutional types into finer groupings for the purpose of indicating probable susceptibilities to certain diseases, an entirely different approach to this problem of type must be devised. From the standpoint of the anthropometrist who is endeavoring only to determine the physical status of an individual and who does not concern himself with susceptibilities to certain specific diseases, these wider categories seem to be entirely adequate. In the remainder of this volume, therefore, we shall speak of body type in terms of a continuous distribution from one extreme which, following Stockard (41), we shall term linear to the other extreme which we shall term lateral. There is considerable evidence to indicate that the distribution of build follows approximately the normal curve.[1]

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[1] Distributions were made of the $\frac{\text{Weight}^{1/3}}{\text{Height}}$ and the $\frac{\text{Chest Circumference}}{\text{Height}}$ indices for seventeen- and eighteen-year-old males. These were analyzed for type of distribution by Pearson's method of moments ($N = 265$).

It will be recalled that where a curve is "normal," according to the Pearsonian notation, $\beta_1 = 0$, $\beta_2 = 3$, $K_2 = 0$. In these distributions, the following constants were found:

| | $\frac{\text{Weight}^{1/3}}{\text{Height}}$ | $\frac{\text{Chest Circumference}}{\text{Height}}$ |
|---|---|---|
| $\beta_1$ | .0426 ± .034 | .0051 ± .004 |
| $\beta_2$ | 3.1580 ± .287 | 2.9620 ± .194 |
| $K_2$ | .1718 ± .320 | — .0419 ± .065 |

There is little doubt that the $\frac{\text{Chest Circumference}}{\text{Height}}$ distribution belongs to the transition type of normal curve, as only one of the constants is more than one probable error away from the theoretical value, and that one is very close. The $\frac{\text{Weight}^{1/3}}{\text{Height}}$ distribution is a little more doubtful, and seems to be very slightly skewed and to lean slightly towards the type IV curve, though here, again, the constants are within one probable error of the normal curve values. The type IV curve fit is slightly better than the fit of the normal curve. (The probable error of $K_2$ in this curve is of a value for which it is very hard to compute the probable error from Pearson's tables, and this value may be somewhat off from its true value). It is quite obvious, however, that both distributions are far from bimodal, as would be demanded by the Kretschmerian theories, and are very close to the type of symmetrical, unimodal distribution of which the normal curve is the classic example.

As will be seen in Chapter IV, normal weight is most highly correlated with height, chest circumference, width of hips, and widths of elbow and knee. These are all measurements which in the factor analysis data given in Tables 4 and 7 are relatively highly correlated with the cross-sectional measurements, with the exception of height, which is added for the purpose of contributing the third dimension to the measurement of volume (weight).

## CHAPTER III

# CRITERIA FOR THE SELECTION OF MEASUREMENTS

For the purpose of selecting anthropometric measurements which may be best adapted to the evaluating of physical status, certain criteria or standards of judgment must first be formulated. These criteria may be best discussed in relation to specific areas of anthropometric appraisement.

For the purpose of evaluating physical status the measurements may be divided into four groups: (1) those which measure general nutritional status, (2) those which measure the amount of subcutaneous fat, (3) those which measure muscular development, and (4) those which measure respiratory condition.

In considering the problem of nutritional status, three approaches to the problem are commonly made by students of applied anthropometry. The first is an attempt to determine the normal or statistically "best" weight of the body, and then to interpret the standard and the actual weight in terms of a percentage of over- and underweight. Over- and underweight are concepts which have been used for centuries by physicians and health workers with no very valid researches to prove their value. Physicians from the time of Hippocrates have believed that a loss of weight or, its equivalent in growing children, failure to grow has frequently been an accompaniment of some organic disease. On the other hand, gain in weight within normal limits has been believed to be an accompaniment of improving health. These normal changes would, of course, exclude abnormal growth in weight due to any form of glandular malfunction which resulted in obesity. The studies in this field have, on the whole, been badly conceived and offer little of value. The clinical experience of dozens of pediatricians and school physicians has upheld the theory that loss of weight or failure to gain, particularly in children, is a bad thing.

This normal weight, as was shown in Chapter II, must be interpreted in terms of the individual's build. The slender, linear type of individual is, and should be, lighter in weight for the same height than the stocky, lateral type of individual. For purposes of predicting what this normal weight should be, some standards must be devised. These will be primarily measurements involving the size of the skeleton both as to dimensions of the thoracic cage and hips, and as to the thickness or coarseness of the long bones. Only when the standard weight has been computed from such fundamental bases can under- and overweight be considered significant enough to be used in directing the hygienic regimen of the child.

The second measurement of nutritional status is the relative amount of fat. The amount of fat underlying the skin needs to be measured and a norm or standard found to determine whether or not the fatty deposits of any given individual are greater or less than the optimum amount. Fat also enters into the problem of under- and overweight, but it is partly a factor to be measured and interpreted separately.

The third measurement used in nutritional status studies is that of the normal development of muscle. This will be considered under two general headings: (1) muscle as it makes up the general nutritional background of the body, and (2) muscle as an organ for strength. It is well established (10)[2] that muscular development is one of the factors determining adequate weight for any given type, and the lack of this muscular development is frequently associated with chronic poor nutrition.

The fourth item, the respiratory condition, in addition to the diagnosis of specific diseases, which is outside the scope of this study, is anthropometrically determined by the relative breathing capacity, or the amount of air the individual can exhale in a forced exhalation following a full inhalation. The standards for normal breathing capacity will be discussed in the second volume. The only effective method at the present time for measuring the relative physiological functioning of the lungs is that used in the physiological laboratory, which is far too complicated for use in everyday practice. Studies using these complicated methods, however, have shown that the respiratory function for any given size of breathing capacity varies as much as 20 per cent; that is, some lungs, particularly when the individual has been in training for a sufficiently long time, transmit more oxygen and carbon dioxide per breath than do other lungs. The breathing capacity of the lungs is easily measured in almost any child above the age of five or six, although much care must be used with the younger children to obtain a maximum record. There is no particular problem as to the technique or the instrument to be used.

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[2] See also Chapter IV.

## GENERAL CRITERIA

Statisticians who analyze anthropometric data and who propose standards based upon such analyses are forced to make certain assumptions, the validity of which determines the validity of their conclusions. One of these assumptions is that the "regression value" of the selected sample may be assumed to be a reasonable "best" standard. We shall try to defend this thesis.

First let us define in nontechnical language the term "regression value." Any one trait or variable in one age of individuals of a single sex will usually distribute itself symmetrically around the average value. The largest number of individuals will lie on or near this average and a rapidly diminishing number will lie farther and farther away from this average. If one were to predict the most probable value of this single variable with no other information than that the individual was of this age and sex, the probable error of prediction would be least if he predicted the average.

Now let us assume a more complicated situation. Suppose that we are attempting to predict the weight of an individual of known age and sex from his chest girth alone. If a distribution be made of weights and chest girths in the form of what is ordinarily called the scatter diagram, it will be seen that, on the whole, individuals with larger chests are heavier and those with smaller chests are lighter. If distributions of weights are made for each size of chest, a best fitting line drawn through the averages of these distributions will be known as a regression line, and from it the most probable weight for one of this age and sex having any given size of chest may be predicted.

Similarly, when more than one variable is used to predict another variable, an algebraic equation may be formed compounding a number of regression equations in a sort of "best weighted" way, so that the variable which one is attempting to predict may be predicted more accurately from these several individual variables than it may be predicted from any one. In other words, the correlation between the variable to be predicted and the value obtained from this compound algebraic equation will be higher than the correlation between the variable and any other combination of the variables upon which the prediction is based. Thus, weight for those of any given age and sex will be predicted more accurately from height, chest girth, width of hips, and width of knee than it will be from any one of those variables alone. This algebraic equation is called a multiple regression equation and is, in effect, the average value for the predicted variable as it would be found from a large sample of individuals having the same height, chest girth, hips, and knee size. The problem before us now is to justify this standard as a "best" standard.

Let us take an illustration from another field. As is well known to those familiar with physiological conditions, variations in the output of the glands of internal secretion affect the functional health of the individual to a very large degree. For example, if the output of the thyroid gland is excessive, the individual grows too rapidly in his long bones, becomes thin and lacking in fat, is nervous, tense, and burns too much energy. If this secretion becomes still greater in amount, the individual becomes definitely diseased. If, on the other hand, the amount of this secretion of the thyroid gland is under the normal amount, other and quite different symptoms appear which are equally distressing and disabling. Something like an average amount seems to be necessary for the best functioning for health. It is also well known that the thyroid gland in its functioning is closely related to the functioning of the pituitary, the suprarenals, and the sex glands. The out-put and function of any one of them is influenced by all of the others.

Let us now assume that the output of each of these glands of internal secretion could be accurately measured. Let us further assume that the size of various internal organs might be known, and we can, of course, assume that the body can be measured so far as its external dimensions are concerned. It would seem then that one might validly assume (1) that the "best average amount" of thyroid output might be determined from the output of the other glands, from the size and functional condition of the viscera, and from the size of the body itself and (2) that the composite average which one would obtain from a multiple regression equation based upon a knowledge of these other variables would represent this average output of the thyroid gland for that particular sized individual who had that particular make-up in the various structures and functions of his body. We should like to advance the theory that such an average, when computed from individuals representing a good sample of the population from the standpoint of health, may be held to represent nature's best experience, and that departures from this average in either direction represent departures into the zones of the abnormal.

Let us now discuss this from the standpoint of the weight of the individual. It is the common experience of medical practitioners that underweight — which is in effect weight less than this average for sex, age, size, and build — is most frequently associated with ill health. Life insurance statistics, on the other hand, indicate that overweight or fatness beyond a certain zone of normality is associated with a shorter life expectancy.[3] In this relationship, too, then it would seem that the average, when computed from a significantly large number of relevant variables, may be defended as being nature's best experience.

The same argument might be extended into many other areas of anthropometric standards, such as muscular development, the size of the breathing capacity, blood pressure, pulse rate, basal metabolic rate, and many other objectively measurable variables. It is difficult to prove this thesis with absolute scientific validity, but we shall assume its validity throughout this study upon the philosophical grounds presented above.

The validity of this multiple regression standard is dependent, of course, upon the sampling from which it is computed. Multiple regressions might be computed from an exceedingly subnormal, malnourished population which would produce standards far below those which could be accepted as desirable. The sample from which these studies have been made is taken largely from the population of the University elementary school, the University high school, and the freshman and sophomore classes of the State University of Iowa in Iowa City. These individuals represent a somewhat superior socio-economic group. The elementary and high schools charge tuition, and most of their population comes from homes of sufficient economic independence to be able to afford to send their children to a private school. It may be held by some that even this population group does not represent ideal living conditions. That is probably true. It is believed, however, that this group represents about as ideal a group as one is apt to find in our population today living under the present American civilization. These standards should be interpreted in the light of this sampling. It is believed that if they depart significantly from a ''good'' average, the departure is on the desirable side rather than on the side of a poor development. It should be noted also that the fact that this group might be slightly larger or better developed than other groups would not affect the standards as they would be applied to other groups, for the multiple regression values are computed for individuals having the same skeletal make-up as the individual measured.

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[3] "It seems clear, therefore, that for persons beyond 30, underweight is distinctly an advantage so far as a favorable prospect of mortality is concerned. It is erroneous to suppose that weight should increase with age, as we have been led to believe by the tables for average weights. This increase with advancing age is, of course, a very common occurrence, but there is every indication that it is a disadvantage and should be carefully avoided. The public health movement in its attack upon the diseases of the adult and later life will do well to bear this fact in mind.

"The body weight of persons in adult and later life gives a fair indication of the amount of work which is thrown upon the digestive, circulatory, and excretory systems. As men grow older, the difficulties of normal functioning of these systems increases with the accumulation of impairments. At the same time, persons as they advance in age seem to grow more inclined to take in more food, especially proteins and fats, and less inclined to indulge in wholesome exercises. This has a tendency to place more and more of a strain upon the food utilization machinery and consequently to hasten the breakdown of the organs concerned in these processes. A realization of these facts on the part of the public would lead, no doubt, to marked changes in habits of diet and exercise, and to an amelioration of conditions which today lead to so much mortality from diseases of the heart, blood vessels and kidneys. There is abundant clinical evidence to prove that through the restriction of conditions premonitory of organic impairment and eventual breakdown of the circulatory and excretory systems have been averted. These facts from life insurance records only tend to reinforce what hygienists have been advocating for years." (2)

The second definite criterion which has been assumed and which also will be defended philosophically is that the best selection of variables for the prediction of the criterion variable is not necessarily the one which gives the highest correlation with the criterion, but is the set of variables which can be assumed both logically and mathematically to be those best adapted to determining what a normal development should be. This can be illustrated by the problem of predicting weight. It has been shown (17) that it is quite possible to use anthropometric measurements and predict weight so accurately as to obtain a multiple correlation of .98. To predict weight this accurately, however, it is necessary to select variables which include fatness and present muscular development as well as the more fundamental bony structures. If in predicting weight one uses not only measurements of the bony skeleton but measurements of the muscle masses of the limbs, taken over fat, and also includes measurements taken over masses of fat, such as the width of the hips over the greater trochanters, one can predict weight almost as accurately as it can be weighed on the scales.

But there would be no point to predicting weight by such a method. It would be much simpler to weigh the person. This method of prediction states in effect that the individual weighs so many pounds because he is so large, so fat, and so well developed muscularly. We shall assume in this series that there are certain fundamental bodily structures which determine more accurately than other accessory structures what a person's normal weight should be. It is further assumed that these accessory structures, such as fat and muscle size, should be disregarded when computing standards for weight, and that these standards should be computed from the skeletal build of the person. This raises the question, is the size or the development of the skeleton at the time the individual is measured normal for his inheritance? It is quite possible that any given individual at some time in the past may have been malnourished or diseased, so that his skeleton remained somewhat smaller or less well-developed than it should be at the present time. An anthropometrist measuring this child today, however, is forced to judge him as he is and to estimate what he should weigh for his skeletal development now. All of the standards proposed in this series of publications are for the individual as per his present skeletal development and maturity and make no attempt to assay his hereditary potentialities as they might have been had they not been changed by favorable or unfavorable environmental influences in the past.

A third general criterion forces us to depart somewhat from strict scientific accuracy and completeness. This criterion is that of simplicity and practicability. As was suggested in Chapter I, any institution or person concerned with child welfare is forced to compromise between scientific completeness and practical usefulness in any large scale service to the individual. Experience has shown that school teachers, nurses, and physicians will not make use of exceedingly complicated standards even though their accuracy be quite superior. They are much more apt to make use of standards which can be measured quickly and accurately and which are simple enough to be computed easily from tables. It is felt, therefore, that we are justified in simplifying these standards in order that they may be more widely used. Many of the standards which we shall propose give multiple correlations with the criterion which are significantly smaller than would be obtained from a larger number of predicting variables. Where this is the case, it will be stated.

## SPECIFIC CRITERIA

### *Prediction of Normal Weight*

1. Measurements which are to be used for the prediction of normal weight should be, so far as possible, measurements of the bony frame of the body rather than measurements of muscular or fatty tissues. Where it is not possible to measure closely enough to the bony framework to be able to disregard overlying tissues, appropriate corrections should be made for fat. Corrections for muscular tissue should be made unnecessary by the proper selection of the places to measure. For example, measuring the circumference of the chest below the pectoralis major muscle will make it unnecessary for the measurer to correct for the influence of this large group.

2. There are three items which must be considered: (a) the measurement or measurements best representing an average cross section of the trunk; (b) the measurement — in this case total height or stature — which best represents the total length of the body; (c) the measurement or measurements best representing the size and coarseness of the bony framework. It is quite possible that one or more measurements may function in more than one of these three ways. For example, measurements of chest and of the hips may have a relatively high correlation with the size and weight of the bones, but there are other and more objective measurements better suited to measuring the bones, such as the width of certain joints.

3. An attempt should be made to use as small a number of measurements as possible in order to produce standards which are usable in ordinary institutional practice and still not lose too much in accuracy of prediction. We may drop from consideration any measurement which "partials out," or whose correlation with the criterion measurement becomes approximately zero when other measurements, which must of necessity be included, are held constant.

### *Measurements of Fat and Subcutaneous Tissue*

The criteria for the selection of measurements of fat and subcutaneous tissue are relatively simple.

1. The battery of measurements selected should have the highest possible correlation with: (a) per cent of under- and overweight and (b) the total amount of adipose tissue on the body relative to

the surface area. This latter "total fat" must of necessity be made up of the sum of a large variety of measurements of fat taken over all parts of the body.

2. The measurements selected should be influenced as little as possible by abnormal distributions of fat.

3. The battery selected should include any measurements which can be used for the purpose of correcting other anthropometric measurements. For example, if the circumference of the chest is to be taken, the fat measurements at the front and back of the chest at the level crossed by the tape in taking the circumference must be included in order that the chest girth may be corrected as accurately as possible to represent a chest with a "standard" amount of fat around it. Similarly, the measurement having the highest relationship to the amount of fat over the crests of the ilia must be included in the battery in order that this important bony measurement may be corrected for fat.

4. The measurements selected should in every case be such that there will be no general adherence between skin and subcutaneous fascia which would render such measurement difficult in certain individuals.

5. The places selected for measurement should be such that no questions of modesty or difficulty of measuring over clothing may arise.

### *Measurements of Muscular Mass*

The fundamental problem is to measure as accurately as possible the relative muscular bulk in order to evaluate the over- or under-development of these muscles. The problem is complicated by one factor which, however, simplifies the criterion: namely, any measurements over muscle masses other than those of the limbs must include the bulk of the thorax or the abdomen in the measurement, and the relative amount of muscular tissue cannot be differentiated from the total bulk of the trunk.

The relative amount of muscle can be measured with a fair degree of accuracy by functional tests of strength. These tests, however, necessitate the purchase of quite expensive equipment, which makes them impracticable in many localities. There is a very high correlation between the strength of the muscles of the trunk and the strength of the muscles of the extremities alone, so that the size of the muscles of the extremities correlates very highly indeed with the strength as obtained by the whole battery. Therefore, the problem of a criterion is relatively simplified. The only thing left to do is measure the circumference of the limbs.

### *Measurement of the Respiratory Function*

Anthropometrically this involves no problem at all. There is only one measurement which is both practicable and useful, and that is the breathing capacity or total amount of air which can be expired by forced exhalation after a full inhalation.

The researches which are discussed in the succeeding chapters of this volume are based upon the criteria presented in this chapter.

## CHAPTER IV

# SELECTION OF MEASUREMENTS

When a survey is made of the various studies that have attempted to prepare standards for the evaluation of physical status, one is struck with the marked lack of unanimity of opinion among the various students of the problem. Many different measurements have been proposed for use,[4] including: standing height; sitting height; trunk length; span of the arms; width of the shoulders between the acromia; width of the shoulders over the deltoid muscles; width of chest, depth of chest, circumference of chest (these three chest measurements have been proposed at three different levels of measurement); the width of the hips at the crests of the ilia; the width of the hips at the trochanters; the widths of the elbow, wrist, knee, and ankle; weight; and breathing capacity. For girths, measurements have been proposed of the girth of the abdomen, the hips, the elbow, wrist, knee, ankle, and of the musculature of the upper arm, forearm, thigh, and calf. Several measurements of the skin, subcutaneous tissue, and fat have been proposed. Hence the first task is to delimit the problem, to evaluate these measurements, and to select the ones that seem best fitted for the purposes of "measuring" physical status in accord with the general criteria listed in the preceding chapter.

To accomplish this task we propose first of all to divide the problem into a number of subproblems and to apply specific analyses to each. So far as this volume is concerned, we shall consider three major divisions:

1. Measurements for the prediction of normal weight
2. Measurements for the prediction of normal fat
3. Measurements for the prediction of normal muscular development

## MEASUREMENTS USED IN THE PREDICTION OF NORMAL WEIGHT

As has been stated previously, the normal weight of the individual is largely determined by his type or build. The problem, then, is to decide what measurements are best adapted to determine normal weight for an individual of given age, height, and build. The selection of the measurements, as was pointed out in Chapter III, should not be based upon the highest correlations with actual weight based upon all possible anthropometric measurements, but on the prediction of a standard weight based upon skeletal measurements alone.

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[4] Measurements of cardio vascular variables for use in the appraisement of present health and of "condition" will not be treated in this volume but will be discussed in a later volume. The measurement of weight and of breathing capacity raises no important problem of conflicting techniques and will not be treated in this volume.

A large number of measurements have been tried, but only a few of these have demonstrated their right to be included in the final battery. Before discussing these researches in detail, it is necessary first to dispose of a number of preliminary problems relating to the techniques of specific measurements. Several of these problems have been solved by experimentation, while solutions here proposed for some of the others are based on philosophical reasoning.

### *Measurements of the Chest*

In all quantitative studies conducted at this laboratory, measurement of the chest has been found more important in weight prediction than measurements of height or of any other commonly used measurements. Differences of opinion have arisen, however, over which of the various methods and levels of measurement of the chest should be selected.

There are three levels in common use: (1) the level of the fourth costo-chondral articulation (usually called the "nipple level" because in measurements on the male the tape or calipers cross the front of the chest at the level of the nipples); (2) the level corresponding to the upper part of the xiphoid cartilage; (3) the level called by Seaver the "ninth rib level." In this measurement the tape is supposed to cross the ninth rib in the axillary line. This measurement is, on the adult, from two to four centimeters lower than the measurement at the level of the xiphoid. The results of these last two measurements are approximately the same.

In measurements of the width of the chest (where the tips of the calipers are passed in front of the bulk of the latissimus dorsi muscles just behind the axillae) it would seem to make relatively little difference as far as weight prediction is concerned which level is selected so long as the measurer is consistent and the formula is based upon that measurement. In measuring the depth of the chest with the flat calipers, and in the measurement of the circumference of the chest at the nipple level, the measurement is affected by the pectoralis major muscles and by the fact that in many cases the instrument rests upon the lower portions of the scapulae. Hence the measurement is skeleton plus muscle plus the deviation added by the thickness of the scapulae and subscapular muscles, and it will vary greatly with the muscularity of the individual. This also permits relatively large changes in the measurements to be made by the slight tensing of these muscles and results in further departures from a measurement of the bony thorax. If the depth of the chest is measured with the curved calipers from sternum to spine, differences of depth due to pigeon breast or funnel chest are most exaggerated at this higher level. These errors can possibly be avoided by the experienced measurer, but it is simpler to guard against the difficulty by selecting measurements at a level at which the errors will not occur, especially in view of the fact that if these measurement methods come into common use, many of the measurers will not be entirely "experienced."

Experiments with the reliability or consistency of the measurements at the nipple and xiphoid levels indicate that there are no significant differences.

A small sample of twenty-five five-year-old preschool children was measured twice in succession on the same day by the same measurer, with but ten minutes interval between the measurements. The reliabilities of the measurements were as follows:

|  | Level |  |
|---|---|---|
| Measurement | Nipple | Xiphoid |
| Chest depth | .982 | .987 |
| Chest breadth | .976 | .978 |
| Chest circumference | .992 | .997 |

It is probable that these reliabilities are much higher than they would be for two different measures, and also higher than they would be if the measurements were taken with a longer interval of time between. High reliabilities are more easily found at this age than later, if the children are used to the measurer, for they do not attempt to secure larger measurements by surreptitiously expanding the chest, as older children sometimes do. The measurements and the techniques of measurement, however, were comparable to one another. Hence for the purpose of assaying the relative reliabilities, they may be taken at face value. These reliabilities are all high and there is no significant difference between them.

Since fluctuations in weight from the norm may be due either to differences in muscular development or to differences in the fat deposits, the measurements selected should be those which will be influenced as little as possible by these two variables. We have, therefore, chosen the level of the xiphoid for all chest measurements for the following reasons:

1. This measurement is below the largest muscle bulks of the chest — the pectoralis major and the latissimus dorsi at its widest part.

2. It is below the scapulae and therefore not unduly influenced either by winged scapulae or by the heavily muscled scapulae of the gymnast.

3. It is below the mammary glands of the female and avoids the difficulties of measurement occasioned by variability in size and position of these glands.

4. The fat is more easily and accurately measured at this level (see Chapter V), so that allowance can readily be made for the influence of this variable on the chest measurements.

5. The xiphoid level is recommended by the international group of anthropologists and is published as the proposed measurement (20, p. 29-30).

The ninth rib measurement suggested by Seaver (39) is not standard in international anthropometry circles and a brief study gave evidence that it offered no advantages over that at the xiphoid level. The landmark is more indefinite and the measurer is apt to vary in his technique. The ninth rib may be hard to locate in many people, while the xiphoid cartilage or the substernal notch is easily palpable. Hence we have given the ninth rib measurement no further consideration here.[5]

In using chest measurements for the prediction of normal weight and normal muscular development, the anthropometrist is faced with the difficulty that the chest measurements of either depth or circumference include a certain amount of muscular tissue. If measured at the level of the xiphoid, this includes primarily the musculature of the erector spinae group, the lower part of the belly of the latissimus dorsi, and, in the circumference and width measurements, some of the lower bundles of the serratus anterior. Thus, any measurements of the chest will include within the tape or calipers this muscular tissue in addition to the thoracic cage itself. If, then, the anthropometrist uses the chest measurements, he is partly "weighing the individual with the tape measure," while if he does not use the chest measurements, he omits the best measurement for the prediction of weight.

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[5] The American Child Health Association (17) has suggested for the measurement of the depth of the chest a technique in which the flat calipers are applied with one arm below the lower angle of the scapula and the other on the front of the chest above the nipple level. This measurement has not been considered by us for several reasons: The landmarks are more indefinite than they seem. The lower angle of the scapula is an extremely variable landmark, differing as much as two interspaces on different individuals. The placement of the calipers on the front of the chest would be greatly influenced by the breast in the postpubescent female, and actual depth would be greatly influenced by the chest muscles. The measurement is not comparable with that used in standard anthropological circles in other parts of the world; but this would not be too important if the measurement were otherwise valuable.

It would seem that in not using these chest measurements much more is lost than is gained, so they have been included, particularly the girth, as perhaps the most important measurement of all. It is felt that the difficulty stated here will be found important only in those possessing an excessively heavy musculature. In such cases the experienced anthropometrist will not easily be mislead, and it is not this group who are, on the average, problems of malnutrition.

The next problem is what chest measurements to use for weight prediction. The measurements suggested in the literature are depth, width, and circumference. In measuring the depth, two methods have been suggested, that with the curved calipers and that with the flat calipers. All measurements at this station have been taken with the flat calipers because it was felt that this gave a better representation of the actual depth of the chest than did the curved calipers, which tend to exaggerate any chest malformations, such as funnel breast or pigeon breast. This seems to be the attitude of the largest proportion of the physical anthropologists — the standard measurement is taken with the flat calipers (20). However, the question is still an open one, and the measurement with the curved calipers may prove to be of greater value.

There seems to be some feeling on the part of anthropometrists in this country (gathered from numerous informal conversations on the subject) that measurements of the circumference of the chest are more difficult of standardization, that the reliability is less, and that a combination of depth and breadth of chest is better adapted to the prediction of weight. This problem has been examined statistically in this laboratory, and the results tend to prove circumference the superior measure. The reliabilities were discussed above, and the circumference was shown to be equally as reliable as either the depth or breadth measurement.

Circumference can be readily corrected for varying amounts of fat, and while such corrections could be carried out for both depth and breadth, the procedure is more complicated and would add to the administrative difficulties.

It now remains to investigate the relative values of depth, width, and circumference for the prediction of weight. In this phase of the investigation, several groups of individuals were used and two approaches to the problem were tried.

In the first approach the measurements taken by Clark were studied. She recorded the cross sections of chests of eleven children (ages seven to nine years) by using a lead tape applied to the thorax and transferring this to cross section paper.[6] The circumference, depth, and breadth were measured directly on this area, and the area itself was measured with the planimeter. She devised the following formula for computing the area from the depth, breadth, and circumference:

$$\text{Area} = W \times D - \left\{ .6036\ [2\ (W\ D) - C] \right\}^2$$

The correlations of area with the three individual measurements and various combinations of the same and the formula were as follows:

| | |
|---|---|
| Actual area and depth | .662 |
| Actual area and width | .572 |
| Actual area and circumference | .975 |
| Actual area and formula | .990 |
| Actual area and width x depth | .871 |
| Actual area and the regression value of width and depth | .888 ($R_{a.dw}$) |

Here it will be seen that when computed against the actual area, Clark's formula gives the highest correlation; but the circumference itself gives a correlation of .975 with area, and this size of correlation is not approached by any other correlation using the variables of depth and width, either singly or combined. The logic of this approach lies in the fact that the chest measurements, to give the highest correlation with weight, should measure as accurately as possible the average cross section of the trunk. Hence the measurement or combination of measurements that correlates best with this cross section should be the best measurement to adopt.

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[6] The cross section in this case was computed by the formula proposed by Clark (11).

The question will be raised, of course, as to whether the Clark formula, developed from the measurements of young children, will be accurate in predicting the cross section of chests of larger persons. No experimental study has been made of this, but we have made the following attempt to verify the formula.

A set of actual chest measurements was taken from the Clark data and each dimension increased 1.5 times, 2 times, and 3 times respectively. Since the same shape of the chest has been retained, the areas would be increased 2.25, 4, and 9 times respectively. The dimensions, the actual areas, and the areas as computed by the formula are given below.

| Measurement | Original Dimensions | x 1.5 | x 2 | x 3 |
|---|---|---|---|---|
| Depth | 14.4 | 21.6 | 28.8 | 43.2 |
| Breadth | 19.6 | 29.4 | 39.2 | 58.8 |
| Circumference | 57.0 | 85.5 | 114.0 | 171.0 |
| Computed area | 238.15 | 535.86 | 952.61 | 2143.36 |
| Actual area | 232.22 | | | |
| Theoretical area | | 535.84 | 952.60 | 2143.35 |

It will be seen that the computed areas and the theoretical areas coincide throughout.

For the next phase of this study the chest measurements of seven age groups of boys and girls were analyzed. These groups were: one to six months, seven to twelve months, thirteen to twenty-four months, twenty-five to thirty-six months, six years, eleven years, fifteen years, seventeen to twenty-five years (college freshmen). Since the approach to the study of infant measurements differed somewhat from that on the other age groups, the findings will be tabulated separately.

A study of these correlations leads to the following conclusions:

1. With the exception of the fifteen-year-old girls, the circumference of the chest has a higher "r" with weight than does either depth or breadth.

2. In the college ages (the only ones where this was tried) for both sexes, circumference gave as high or higher correlation than did either cross section or width times depth.

3. At all ages except eleven-year-old girls, when circumference was held constant with either depth, breadth, or both (as $r_{02.4}$, $r_{02.34}$, or $R_{0.23/4}$), the resulting partial "r" was lower than when either of

Table 9

Analysis of Chest Measurements as Predictors of Weight†

| Correlation* | Boys | | | | Girls | | | |
|---|---|---|---|---|---|---|---|---|
| | Age Group | | | | | | | |
| | 6 Years | 11 Years | 15 Years | College | 6 Years | 11 Years | 15 Years | College |
| $r_{02}$ | .5285 | .6962 | .732 | .6765 | .5823 | .7526 | .6957 | .6159 |
| $r_{03}$ | .6139 | .8324 | .721 | .6775 | .7648 | .7907 | .6301 | .6976 |
| $r_{04}$ | .8145 | .8414 | .820 | .7921 | .8489 | .8487 | .6582 | .7919 |
| $r_{05}$ | | | | .7926 | | | | .7633 |
| $r_{06}$ | | | | .7921 | | | | .7416 |
| $r_{02.3}$ | .3165 | .3656 | .525 | .6076 | .2513 | .4790 | .5122 | .4795 |
| $r_{02.4}$ | .0307 | .1050 | .313 | .2840 | −.0332 | .1582 | .4100 | .1078 |
| $r_{03.2}$ | .4712 | .6955 | .503 | .6081 | .6416 | .5783 | .3716 | .6023 |
| $r_{03.4}$ | −.0496 | .3794 | .142 | .2034 | .1294 | .2826 | .2776 | .2256 |
| $r_{04.2}$ | .7307 | .4312 | .606 | .6274 | .7600 | .6102 | .2937 | .7047 |
| $r_{04.3}$ | .6791 | −.1005 | .576 | .5830 | .5816 | .5706 | .3639 | .5566 |
| $r_{04.23}$ | .6338 | .2880 | .413 | .2774 | .5422 | .3371 | .1159 | .4891 |
| $R_{0.23}/_4$‡ | .0592 | .4026 | .333 | .4011 | .1330 | .1676 | .4743 | .2079 |
| $R_{0.24}/_3$ | .6794 | .4460 | .634 | .6463 | .5834 | .5630 | .5217 | .6538 |
| $R_{0.34}/_2$ | .7311 | .7246 | .620 | .6475 | .7646 | .4856 | .3869 | .7178 |
| $R_{0.23}$ | .6628 | .8567 | .808 | .8113 | .7823 | .7913 | .7452 | .7775 |
| $R_{0.24}$ | .8147 | .8433 | .840 | .8192 | .8490 | .8531 | .7270 | .8292 |
| $R_{0.34}$ | .8150 | .8660 | .824 | .8018 | .8516 | .8643 | .6905 | .7330 |
| $R_{0.234}$ | .8152 | .8695 | .844 | .8281 | .8518 | .8681 | .7491 | .8361 |
| $R_{2.34}$ | .6327 | .7881 | .745 | .6708 | .7011 | .7583 | .7461 | .7177 |
| $R_{4.23}$ | .8228 | .9156 | .877 | .8472 | .8924 | .9098 | .8328 | .8687 |
| $R_{3.24}$ | .7764 | .8700 | .824 | .7185 | .8599 | .8356 | .7487 | .4686 |

* The following is the key to be used with this table:

| | |
|---|---|
| 0 = Weight | 4 = Chest Circumference (Xiphoid Level) |
| 1 = Height | 5 = Cross Section of Chest (By Formula) |
| 2 = Chest Depth | 6 = Width x Breadth |
| 3 = Chest Width | |

† In this monograph, correlation coefficients and some other statistical constants have been carried to the fourth decimal as a routine practice. This is farther than is the current practice, in view of the probable errors of such statistical results. The reason for our doing so is that in case any readers of this monograph wish to proceed with partial correlations or other studies based upon these data, it will be possible for them to do so without the probability of introducing other errors due to successive rounding off. The probable error is not an "error" of the particular data presented and studied, but of these data when they are used as representative of all individuals in that particular statistical universe. Within the error of measuring (not of sampling), the correlations are the correlations between these particular variables, with these particular cases. To introduce possible errors other than those of measurement by the successive rounding off of correlation coefficients does not seem to us to be justified by the facts.

‡ Multiple correlations of the nature of $R_{0.23}/_4$ may be read as meaning the

the other variables was held constant and the other two correlated against weight. This would indicate that, in general, circumference "contains more" of what makes up weight than does either depth or width.

4. In all multiple correlations between combinations of these three variables and weight, (as $R_{0.23}$, $R_{0.24}$, or $R_{0.234}$), the ones containing circumference were higher than those not containing circumference, except for eleven-year-old girls.

5. In all age groups, multiple correlations of $R_{4.23}$ were higher than either $R_{2.34}$ or $R_{3.24}$. In other words, circumference predicts the best combination of depth and breadth better than either depth or breadth combined with circumference predicts the other.

6. In all age groups except eleven-year-old girls, the correlation of circumference with weight is within .035 (about one probable error) of the correlation of the best combination of all three variables with weight.

7. In all groups except eleven-year-old girls, eleven-year-old boys, and college men, the correlation of circumference with weight was higher than the best correlation of weight with the best weighted combination of depth and breadth. In eleven-year-old boys, it differed .015, and in college men, .02.

With infants, total length was held constant throughout to avoid the influence of spuriously high zero-order correlations, since the comparative age range was greater. However, the regressions within each range were linear.

From Table 10 the following conclusions may be verified:

1. In the zero-order correlations the correlation of weight with circumference is in every case higher than that of depth or width.

2. The same is true when height is held constant ($r_{03.1}$).

3. When one chest variable and height are held constant, and either of the other two is correlated with weight ($r_{02.14}$), the partial correlation is lower when the circumference is held constant than when either of the other chest measurements is held constant.

4. When two chest variables and height are held constant, and

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partial correlation between the variable zero and the best regression equation weighting of variables 2 and 3 for the prediction of variable 0, with variable 4 held constant. The general formula for this type of correlation is:

$$R_{0.123\,\ldots\,k/m\,\ldots\,n} = \sqrt{1-(1-r^2_{01.m\ldots n})(1-r^2_{02.1m\ldots n})(1-r^2_{03.12m\ldots n})\ldots\ldots(1-r^2_{0k.123\ldots(k-1)m\ldots n})}$$

## Table 10
## Analysis of Chest Measurements as Predictors of Weight

| Correlation* | Age, Months | | | |
|---|---|---|---|---|
| | 1 to 6 | 7 to 12 | 13 to 24 | 25 to 36 |
| | **Boys** | | | |
| $r_{02}$ | .718 | .559 | .398 | .561 |
| $r_{03}$ | .855 | .704 | .520 | .399 |
| $r_{04}$ | .891 | .773 | .710 | .784 |
| $r_{02.1}$ | .477 | .384 | .251 | .538 |
| $r_{03.1}$ | .634 | .493 | .314 | .167 |
| $r_{04.1}$ | .699 | .663 | .552 | .736 |
| $r_{02.13}$ | .240 | .319 | .225 | .662 |
| $r_{02.14}$ | .200 | .087 | .148 | .008 |
| $r_{03.12}$ | .520 | .450 | .294 | −.480 |
| $r_{03.14}$ | .427 | .129 | .105 | −.137 |
| $r_{04.12}$ | .603 | .590 | .523 | .596 |
| $r_{04.13}$ | .548 | .521 | .487 | .734 |
| $r_{02.134}$ | .077 | .106 | .145 | .239 |
| $r_{03.124}$ | .392 | .142 | .102 | −.281 |
| $r_{04.123}$ | .512 | .445 | .462 | .474 |
| $R_{0.23/1}$ | .683 | .565 | .388 | .496 |
| $R_{0.24/1}$ | .712 | .665 | .566 | .716 |
| $R_{0.34/1}$ | .762 | .664 | .556 | .731 |
| $R_{0.234/1}$ | .765 | .674 | .572 | .759 |
| $R_{0.23/14}$ | .432 | .170 | .179 | .274 |
| $R_{0.24/13}$ | .552 | .529 | .503 | .741 |
| $R_{0.34/12}$ | .679 | .600 | .520 | .635 |
| | **Girls** | | | |
| $r_{02}$ | .827 | .630 | .407 | .479 |
| $r_{03}$ | .791 | .732 | .230 | .617 |
| $r_{04}$ | .887 | .760 | .655 | .714 |
| $r_{02.1}$ | .333 | .392 | .206 | .398 |
| $r_{03.1}$ | .264 | .457 | .138 | .456 |
| $r_{04.1}$ | .440 | .562 | .482 | .637 |
| $r_{02.13}$ | .318 | .217 | .191 | .266 |
| $r_{02.14}$ | .166 | .017 | −.115 | −.058 |
| $r_{03.12}$ | .243 | .330 | .112 | .355 |
| $r_{03.14}$ | .019 | .164 | .056 | −.015 |
| $r_{04.12}$ | .344 | .438 | .457 | .544 |
| $r_{04.13}$ | .366 | .399 | .469 | .500 |
| $r_{02.134}$ | .174 | −.004 | −.117 | −.062 |
| $r_{03.124}$ | .054 | .164 | .061 | −.026 |
| $r_{04.123}$ | .256 | .343 | .449 | .442 |
| $R_{0.23/1}$ | .400 | .496 | .232 | .509 |
| $R_{0.24/1}$ | .477 | .561 | .488 | .639 |
| $R_{0.34/1}$ | .441 | .574 | .484 | .628 |
| $R_{0.234/1}$ | .468 | .579 | .495 | .639 |
| $R_{0.23/14}$ | .176 | .167 | .130 | .063 |
| $R_{0.24/13}$ | .400 | .399 | .481 | .504 |
| $R_{0.34/12}$ | .348 | .453 | .450 | .544 |

* The following is the key to be used with this table:

0 = Weight
1 = Height
2 = Chest Depth
3 = Chest Width
4 = Chest Circumference (Xiphoid Level)
5 = Cross Section of Chest (By Formula)
6 = Width x Breadth

the other chest variable is correlated with weight ($r_{02.134}$), the partial correlation is lower with circumference as one of the variables held constant than when the other two are held constant.

5. Multiple correlations with height held constant ($R_{0.23}/_1$) are higher between any combinations of two chest variables where one is circumference, than with depth and breadth alone.

6. In multiple correlations with weight, in which height and one other chest variable are held constant ($R_{0.23}/_{14}$), the multiple correlation is smaller when circumference is held constant than when it is not.

7. In every case, $r_{04.1}$ (the correlation of chest circumference and weight, with height held constant) is larger than $R_{0.23}/_1$ (the multiple correlation of the best weighted combination of depth and breadth with weight, with height held constant).

This analysis leads to the conclusion that in practically all age groups tried — and these age groups represent a fair sampling of both sexes up the age range — circumference correlates with weight to a higher degree than other chest measurements, and in ages where this is not so, the difference is usually less than one probable error of the correlation coefficient. This indicates strongly that the circumference of the chest is a better measurement than any other single chest dimension, and is usually better than the best combination of depth and breadth.

Since measurements of the chest are included in the multiple regression formulae for the prediction of normal weight largely for the purpose of adding the best possible measurement of the cross sectional skeletal component, further evidence that the circumference is the best of the three chest measurements may be adduced from the factor analysis of the anthropometric variables. For convenience, the corrected factor loadings of the cross sectional component from Tables 4 and 7 in Chapter II are reproduced here. These represent zero-order correlations with this growth component.

| Age Years | Width | Depth | Girth |
|---|---|---|---|
| | | Male | |
| 4 | .22 | .41 | .52 |
| 6 | .55 | .55 | .74 |
| 10 | .44 | .60 | .59 |
| 14 | .25 | .29 | .36 |
| College | .65 | .67 | .84 |

| Age, Years | Width | Depth | Girth |
|---|---|---|---|
| | Female | | |
| 4 | .58 | .73 | .80 |
| 6 | .25 | .26 | .48 |
| 10 | .47 | .63 | .67 |
| 13 | .59 | .62 | .71 |
| College | .60 | .69 | .80 |

It will be seen that with the exception of the ten-year-old males, the circumference is more heavily weighted with the cross sectional component than is either depth or width, and the difference in this age group is negligible. This is further confirmatory evidence of the relatively greater value of circumference as the "best" of the chest measurements, so far as predicting normal weight is concerned.

Finally, when it is possible to use only one measurement to do the work of two or three without losing too much effectiveness, this should be done; for the simpler the administration of such methods of anthropometric appraisement, the more they are apt to be used. Hence we have decided to use circumference of the chest measured at the xiphoid level as the best measurement of the chest variable for the prediction of weight.

*Corrections for Anomalies of Chest Shape.* — In certain situations, very seldom met with, it may be desirable to measure depth and width of the chest for the purpose of correcting for too deep or too flat chests. We have shown above that the circumference of the chest correlated better with cross section of the chest than did the best combination of depth and width, even when multiplied together. There are times, however, when this circumference-cross section relationship is not reliable. For example, let us consider the following artificial conditions: Suppose we have an area of 4 square inches arranged in the form of a square, 2 inches on each side. The perimeter or circumference will be 8 inches. If this is arranged in the form of a rectangle, 1 inch x 4 inches, the perimeter or circumference is 10 inches. In like manner, very wide, shallow chests will have spuriously larger circumferences than normal chests, and the reverse will be true of narrow, flat, anthropoid chests. To compensate for this fact, a correction factor in the form of a regression equation based on the chest index, $\frac{\text{Chest depth}}{\text{Chest width}}$, may be used.

$$\begin{aligned} \text{Let } Y &= \frac{\text{actual weight}}{\text{normal weight}} \\ X &= \text{the chest index} \\ \text{Then } Y &= .20X + .867 \end{aligned}$$

Divide the actual over- or underweight decimal by this number to secure the "corrected over- or underweight."

For example, if the chest index is .64, (the average is about .71), Y would equal $.2 \times .64 + .867 = .987$. Assume that the child's weight index, Y, is .97. He may then be assumed to be $\frac{.97}{.987}$ or .983 times normal weight. It will be seen that even with this large deviation in chest index, the correction is slight.

### *Measurements of the Hips*

Of the three measurements of the hips proposed in the literature — width at the crests of the ilia, width at the level of the trochanter, and the circumference over the largest part of the glutei — the first seemed on *a priori* grounds to be the one of choice. Since the purpose of the measurement is to predict normal weight for a given skeletal framework, the major criterion is that it should measure the bony pelvis and should not be unduly influenced by muscle and fat.

The distribution of the fat of the body is not uniform. In addition to the fat distributed just under the skin over almost the whole of the surface of the body, there are other accumulations of fat in what have been called fat pads. One of the most important of these is located on the sides and rear of the hips below the crests of the ilia, and over the outside of the greater trochanters and the upper part of the thighs. When the hip width is measured at the level of the trochanters, this measurement is made over these fat pads on either side; hence, this measurement differs more widely from the actual bony width than does the measurement taken at the level of the crests of the ilia. Since it has been proposed in a recent study (17) to measure the width at the level of the trochanters, it was felt that some further study of this problem should be made. X-ray pictures were taken of the hips at the two levels with metal calipers held in place with the usual amount of pressure.

Over the normal range of plumpness, the difference between the caliper and the bone varied at the level of the crests from 1 to 5 millimeters in males and from 1 to 8 millimeters in females. Measurements at the level of the trochanters varied from 1 to 8 millimeters in males and from 15 to 23 millimeters in females. In stouter individuals the deviations were greater. In one stout male the deviation was 19 millimeters at the crests and 39 millimeters at the trochanter. In one stout female the deviation was 15 millimeters at the crests and 63 millimeters at the trochanter. It should be remembered that these are deviations on one side only and that the variations in measurement will really be twice this amount. There is a need for a corrective factor to be applied if the measurement is to be a truly skeletal one.

This correction is made from a "fat measurement" with the calipers devised for this purpose,[7] and is best obtained at a place where the skin and underlying layer of fat can be readily picked up in a double fold. This correction is more easily applied to the bi-cristal measurement from a skin and fat measurement made just above this point, than it is to the trochanter measurement. At the latter place, the fat is frequently too thick to pick up in a double fold, is much more adherent, and there is a larger fat pad present. This pad does not extend over the crest.

The measurement of the circumference of the hips presents all of the shortcomings of the measurement of width at the trochanters, and is, in addition, complicated by varying muscular development of the gluteal muscles. There seems little doubt that the measurement to be selected should be the measurement of the width at the crests of the ilia. Hence this has been adopted for use at this Station without further study.

It should be pointed out that if it were possible to measure the width at the trochanters as accurately as it can be measured at the crests of the ilia, it would probably be wise to measure both. Individual differences at the top in the flare of the pelvis introduce a certain error of prediction. At the present time this could be avoided only by the use of the X-ray, which is impractical. The only safeguard is in having an experienced measurer who observes carefully and uses good judgment in connection with his mathematical computations.

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[7] These calipers are secured from the American Public Health Association, 50 West 50th Street, New York City.

*Measurements of the Bones of the Limbs*

In the prediction of body weight it seemed logical to assume that individuals with a heavier bony build should weigh more than those with smaller bones. The size of the chest and the width of the hips give a partial estimate of the bony framework. It was felt that there was a need for measurements of the bones of the extremities of the body as well. There seemed to be only four places at which these measurements might be taken in such a way as to secure a reasonably close approach to the bony structures. These places were the width of the elbow over the epicondyles of the humerus, the width of the wrist at the distal extremity of the forearm just proximal to the carpal bones, the width of the knee at the epicondyles of the femur, and the width of the ankle taken with the flat

Table 11

Analysis of Joint Measurements as Predictors of Weight

| Correlations* | Years Months | Years Months | Years Months | College Freshmen | Years Months | Years Months | Years Months | College Freshmen |
|---|---|---|---|---|---|---|---|---|
| | 5 6 to 9 5 | 9 6 to 14 5 | 14 6 to 17 5 | | 5 6 to 9 5 | 9 6 to 13 5 | 13 6 to 17 5 | |
| $r_{01}$ | .7328 | .8446 | .6432 | .5518 | .6046 | .7778 | .4466 | .6948 |
| $r_{02}$ | .6645 | .7724 | .6663 | .3230 | .6801 | .7278 | .4899 | .5518 |
| $r_{03}$ | .8519 | .8972 | .7461 | .5338 | .8789 | .8176 | .6861 | .8027 |
| $r_{04}$ | .8091 | .6341 | .5836 | .4793 | .6726 | .6804 | .3769 | .3686 |
| $r_{01.2}$ | .5350 | .5954 | .3160 | .5366 | .3506 | .5297 | .2525 | .5850 |
| $r_{01.3}$ | .2802 | .5237 | .4915 | .6067 | .2817 | .4664 | .1390 | .4256 |
| $r_{02.1}$ | .3730 | .3026 | .3825 | .2882 | .5070 | .3787 | .3334 | .3400 |
| $r_{02.3}$ | .1188 | .1805 | .3044 | .0924 | .2088 | .3783 | .1295 | .3015 |
| $r_{03.1}$ | .6731 | .7118 | .6184 | .5903 | .8184 | .5859 | .5930 | .6610 |
| $r_{03.4}$ | .5010 | .8209 | .5968 | .3910 | .7678 | .6610 | .6199 | .7697 |
| $r_{04.3}$ | .2384 | .0172 | .2056 | .2958 | .1100 | .2964 | −.0591 | .0996 |
| $r_{02.13}$ | .0632 | −.0788 | .1084 | .0143 | .1297 | .2170 | .0910 | .2154 |
| $r_{04.13}$ | .1868 | −.0332 | .0814 | .0985 | .0395 | .1928 | −.0800 | .0814 |
| $R_{0.13}/_{24}$ | .5119 | .7867 | .4747 | .6386 | .7385 | .6299 | .5561 | .7698 |
| $R_{0.24}/_{13}$ | .1891 | .0820 | .1502 | .0994 | .1297 | .2572 | .1335 | .2154 |

* The following is the key to be used with this table:

$x_0$ = Weight
$x_1$ = Elbow
$x_2$ = Wrist
$x_3$ = Knee
$x_4$ = Ankle

calipers over the malleoli with the blades of the caliper parallel to the inside of the foot.

Four age groups for each sex were used in the first study. The groupings were coarse, but they were selected because linearity of regression was found throughout each range. The age groups were as follows: Males: 5 years, 6 months to 9 years, 5 months; 9 years, 6 months to 14 years, 5 months; 14 years, 6 months to 17 years, 5 months; and college freshmen. Females: 5 years, 6 months to 9 years, 5 months; 9 years, 6 months to 13 years, 5 months; 13 years, 6 months to 17 years, 5 months; and college freshmen. An analysis of the resulting intercorrelations shows the following facts, which can be verified from Table 11.

1. With but three exceptions, the zero order correlation of elbow with weight was larger than that of wrist with weight; and without exception the zero order correlation of knee with weight was larger than that of ankle with weight.

2. In all but the three exceptions noted above, the partial correlation between weight and elbow with wrist held constant ($r_{01.2}$) was larger than the partial correlation of wrist and weight with elbow held constant ($r_{02.1}$).

3. In every case the partial correlation of weight and knee with ankle held constant ($r_{03.4}$) was larger than the partial correlation of weight and ankle with knee held constant ($r_{04.3}$).

4. In all cases the correlation of weight with either wrist or ankle (elbow and knee held constant) was very small, so small as to influence a multiple correlation very little indeed.

5. A correlation of weight with the best regression weighting of elbow and knee (wrist and ankle held constant) ($R_{0.13}/_{24}$) was relatively large; while the reverse, the correlation of weight with the best regression weighting of wrist and ankle with elbow and knee held constant ($R_{0.24}/_{13}$) was small.

6. When weight was correlated with knee (elbow held constant) ($r_{03.1}$), the correlation was in every case high, while when weight was correlated with elbow and knee was held constant, the correlation was somewhat lower. This would indicate that in general knee contributes more to the prediction of weight than does elbow.

7. When wrist and weight were correlated and knee held constant, the correlation was very low.

It would seem clear from this picture that the measurements of wrist and ankle contribute relatively little to the total predictive value if elbow and knee are used for the prediction equation. In further studies, wrist and ankle were omitted from consideration, but elbow and knee seemed to be worthy of further study.

A second study of the effect of bony measurements on the weight was made by measuring the bones of thirty-nine adult male matched skeletons[8] and correlating these measurements with the actual weight of the whole skeleton. The correlations obtained were less than the true value as the weights of the skeletons were inconsistent due to differences in the amount of drying out and in the amount of fat left inside of the bones. This was impossible to standardize. Consequently, these correlations are decidedly lower than they would be if the studies could have been made on fresh bones.

The data available on the skeletons were the stature of the cadaver as recorded in the records of the laboratory, the length of the left clavicle, the widths of the humerus and the femur at the epicondyles, and the width of the pelvis.[9] This was obtained by assembling the pelvis and binding it together with rubber bands, and then measuring it at the crests of the ilia. The results are seen in the following tabulation:

Zero Order Correlations*

$r_{01} = .5874$
$r_{02} = .4334$
$r_{03} = .4570$
$r_{04} = .5922$
$r_{05} = .5664$
$r_{12} = .4751$
$r_{13} = .4472$
$r_{14} = .6130$
$r_{15} = .5518$
$r_{23} = .4156$
$r_{24} = .3621$
$r_{25} = .4579$
$r_{34} = .5818$
$r_{35} = .6748$
$r_{45} = .6505$

Partial and Multiple Correlations*

$r_{01.2345} = .2537$
$r_{02.1345} = .0091$
$r_{03.1245} = .2325$
$r_{04.1235} = .1672$
$r_{05.1234} = .1424$
$r_{0.1345} = .2533$
$r_{03.145} = .2408$
$r_{04.135} = .1889$
$r_{05.134} = .1452$
$r_{02.134} = .0299$
$r_{02.135} = .0894$
$r_{02.145} = .0647$
$r_{02.345} = .0038$
$r_{02.34} = .0352$
$r_{02.35} = .1005$
$r_{02.45} = .0878$
$R_{0.12345} = .6873$
$R_{0.1345} = .6872$
$R_{0.134} = .6789$
$R_{0.135} = .6728$
$R_{0.13} = .5542$
$R_{0.45} = .6712$
$R_{0.35} = .5746$

* The following key is to be used with the above tabulation:

0 = Weight
1 = Height
2 = Shoulder
3 = Pelvis
4 = Elbow
5 = Knee

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[8] These measurements were made on skeletons of the anatomical laboratory of Washington University through the courtesy of the director of the laboratory, Dr. R. J. Terry. The actual measurements were made by Dr. Helen Dawson of this Station.

[9] It was impracticable to attempt to assemble the bones of the wrist and ankle in such a way as to obtain a measurement of the widths of these joints that would be even approximately accurate.

From this tabulation it can be seen that the length of the clavicle, which was the nearest approach possible to the width of shoulders, makes little difference if the measurements of hips and either elbow or knee are taken. There is other evidence, to be presented below, that if the chest girth is also included (which was not practicable for the skeletons), the importance of shoulder width is further diminished. Hence this measurement is dropped from further consideration in so far as its effect upon the prediction of the weight of the skeleton is concerned.

This tabulation also indicates that the widths of the elbow and knee alone are much more accurate than stature and hips, and are almost as accurate as the whole battery of measurements for the prediction of skeletal weight. This is the more surprising in that the width of these bones at the epicondyle correlates with the size of the bone at the shaft only .67 for the humerus and .52 for the femur.

Since the bony skeleton does make up an important part of the weight of the body, it seems desirable to retain the measurements that correlate highly with the bony skeleton in any regression formula that is used for the prediction of body weight until there is evidence to the contrary.

It was impossible to measure chest girth on the skeletal material, but the question arises as to whether the inclusion of it would make it possible to eliminate the elbow measurement. If the circumference of the chest were correlated highly enough with the elbow, the elbow measurement might be eliminated from the regression equation and simplify the administration procedure. An attempt to solve this problem was made on the living.

As has been stated, it was found that the variables of height, chest circumference, width of hips, width of elbow, and width of knee were of importance for the prediction of normal weight. Comparative studies were made to determine the multiple correlations predicting weight when using height, girth of chest, width of hips, knee, and elbow, and in using the same measurements without elbow width. The results are seen in Table 12. It will be seen that there is very little difference in the resulting multiple correlations at any age. Therefore, to facilitate the computation, it was decided to omit the width of elbow in weight prediction, although an occasional exceptional case might warrant its inclusion.

To justify the inclusion of any joint measurements, analyses were

Table 12

Comparative Multiple Correlations Predicting Weight for Three Different Groups of Skeletal Measurements

| Age | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | Group 1* | Group 2** | Group 3*** | Group 1* | Group 2** | Group 3*** |
| 2 Years to 2 Years, 5 Months | .9458 | .9098 | | .9791 | .9266 | |
| 4 Years | .9303 | .9124 | .8752 | .9666 | .9636 | .9576 |
| 5 Years | .9353 | .9100 | .8972 | .9508 | .9442 | .9378 |
| 6 Years | .9265 | .9224 | .9206 | .9059 | .8972 | .8875 |
| 7 Years | .9097 | .9042 | .8941 | .9433 | .9340 | .9298 |
| 8 Years | .9350 | .9247 | .9105 | .9106 | .9077 | .8880 |
| 9 Years | .9410 | .9237 | .9120 | .9481 | .9481 | .9327 |
| 10 Years | .9248 | .9180 | .9113 | .9339 | .9315 | .9153 |
| 11 Years | .9061 | .9011 | .8726 | .9385 | .9385 | .9237 |
| 12 Years | .9068 | .8960 | .8759 | .9298 | .9289 | .9027 |
| 13 Years | .9741 | .9682 | .9533 | .9313 | .9279 | .8983 |
| 14 Years | .9585 | .9573 | .9467 | .9066 | .9041 | .8662 |
| 15 Years | .9517 | .9500 | .9359 | .8495 | .8480 | .7865 |
| 16 Years | .9211 | .9196 | .9034 | .8759 | .8749 | .7426 |
| 17 Years | .9266 | .9233 | .9037 | .8756 | .8729 | .7977 |
| College | .8986 | .8946 | .8753 | .9275 | .9275 | .7966 |

* Group 1 includes height, chest circumference, hips, knee, and elbow
** Group 2 includes height, chest circumference, hips, and knee
*** Group 3 includes height, chest circumference, and hips

made for each age and sex from four years to college freshmen, and these results are also tabulated in Table 12. It will be seen that the inclusion of measurements of joints is of less importance in males than in females, and more in females after pubescence (twelve to thirteen) than before. For some reason, as yet not known, the bone measurements become of greater and greater importance in the female as postpubescent age increases, at least to the age of college freshmen. In the methods devised at this Station, "normal weight" is read from two charts, each giving regression values for two measurements (with constants of the equation incorporated into the tables), and it is as easy and hardly more time consuming to compute this from four measurements as from three; hence, we have left the knee measurement in, even in ages where it makes relatively little difference. This decision has been strengthened by experience with a number of somewhat atypical or asymmetrical individuals, in which cases the prediction of the norm is better, or nearer to the probable facts as ascertained by observation, when the knee measurement is included.

Studies with the X-rays have shown that within a very large range of fatness the amount of fat over the epicondyles of knee and elbow makes little difference in the measurements. This is not true, however, of the very corpulent, and the addition of the measurement of knee or of elbow and knee may increase the predicted normal weight more than is desirable. As yet no satisfactory method has been devised to correct for this because of the fact that the skin with its subcutaneous fat is quite adherent to the underlying fascia in the regions of joints and cannot be consistently picked up and measured at those points. However, the cases of extreme corpulency are not frequent, and the measurer soon learns to make any necessary allowances for them. It may be pointed out that from the standpoint of using these standards constructively for the benefit of the child, this makes little difference. The important thing is not that one should be able to predict the amount of overweight to the tenth of a kilogram, for if the child is overweight he is at least well nourished, so far as weight is an indication of nourishment. The important thing is to evaluate the nutritional status of the child who is near the normal and the child who is below. It is found that these measurements of joints are accurate within this range. The pressure used presses the epicondyles through the fat for all those whose weight is not more than 8 or 10 per cent above the normal; hence these measurements assist in identifying the "normal" weight for the normal and the underweight child, which is the important aspect of this problem from the standpoint of child welfare.

As tentative conclusions the evidence adduced above would indicate that for the purpose of measuring the relative contribution to weight of the bony skeleton, the measurements of height and the widths of hips, knee, and elbow add definitely to the multiple correlations for the prediction of skeletal value. It is probable that the circumference of the chest is also of value, though it has been impossible to verify this on the matched skeletons. When the measurement of the width of knee is included, the necessity for adding the measurement of the elbow is lessened. Further studies on the living in which total weight — not skeletal weight — was predicted indicated that the measurements of the elbow and knee were of lesser importance in the males, and in the females were of great importance only after the age of thirteen. Since it is practically as easy, administratively, to add the measurement of the knee as it is to omit it, it is recommended that it be included to conserve the slight increase in accuracy. In both sexes, it was found that the addition of the width of the elbow added too little to pay for its retention.

### *Other Measurements Suggested in the Literature*

Preliminary studies had indicated that there was nothing of importance to be gained by the inclusion of the measurements of width of shoulders and of sitting height, frequently mentioned in the literature as being of value in the prediction of weight. Data on these measurements were analyzed for infants and older children. In the data on infants, the width of the knee was not included, but even without this, the results indicated that measurements of sitting height and shoulders might be omitted. These results are seen in Table 13.

In every case, total height with chest girth and width of hips held constant correlates more highly with weight than does sitting height with chest girth and hip width held constant. The correlation of height against weight with sitting height, chest girth, and hip width held constant is in every case higher than the correlation of weight and sitting height with total height, chest girth, and width of hips held constant. In other words, in this combination, total height contributes more to the prediction of weight than does sitting height, giving the same kind of information but more of it.

When the width of the shoulders is correlated against weight with height, chest, and hips held constant, the partial correlation is very low. In infants, neither sitting height nor shoulder width nor both contribute enough to raise the multiple correlation more than .01 — a contribution too small to make the inclusion of either measure desirable.

### *Size of the Head*

Since the head is such a comparatively large part of the infant's body, it was thought that head size might contribute much to the prediction of normal weight. The circumference of the head was added to the battery for trial, but in no case did it add more than .01 to the multiple correlation. The partial correlation of head circumference and weight with height, chest, and hips constant was .18 in the age group studied; hence this measurement has been omitted.

Table 13

Analysis of Relative Contributions of Sitting Height and Width of Shoulders to the Prediction of the Weight of Infants

| Multiple Correlations* | Age, Months | | | |
|---|---|---|---|---|
| | 1 to 6 | 7 to 12 | 13 to 24 | 25 to 36 |
| | | Boys | | |
| R | .950 | .955 | .852 | .882 |
| $r_{01.23}$ | .473 | .745 | .532 | .519 |
| $r_{05.23}$ | .398 | .660 | .383 | .456 |
| $r_{05.123}$ | .062 | .219 | .018 | .110 |
| $r_{06.123}$ | .128 | −.054 | .255 | .209 |
| $r_{01.235}$ | .284 | .498 | .399 | .293 |
| | | Girls | | |
| R | .951 | .931 | .862 | .891 |
| $r_{01.23}$ | .594 | .650 | .581 | .613 |
| $r_{05.23}$ | .498 | .452 | .489 | .448 |
| $r_{05.123}$ | .063 | −.123 | .024 | −.043 |
| $r_{06.123}$ | −.100 | −.004 | .051 | .003 |
| $r_{01.235}$ | .378 | .534 | .362 | .468 |

* The following is the key to be used with this table:
0 = Weight
1 = Height
2 = Chest Circumference
3 = Hips
4 = Knee
5 = Sitting Height
6 = Shoulders

The second phase of this study was made on ages four, six, ten, thirteen (girls), fourteen (boys), and college freshmen. Multiple correlations were run predicting weight from height, chest girth, hip width, and width of knee, and for these plus shoulder width and sitting height. Partial correlations of sitting height and of shoulder width on weight, with height, chest, hips, and knee constant were also computed. From Table 14 it will be seen that in no case do either of these measurements add more than .01 to the multiple correlation. For this reason these measurements were omitted, and we chose total height, circumference of chest (corrected for fat), width of hips at the crests of the ilia (corrected for fat), and the width of the left knee as the skeletal measurements from which to compute normal weight for all age groups.

Table 14

Analysis of Relative Contributions of Sitting Height and Width of Shoulders to the Prediction of Weight*

| Multiple Corre-lation | Males | | | | | Females | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 4 Years | 6 Years | 10 Years | 14 Years | College | 4 Years | 6 Years | 10 Years | 13 Years | College |
| $R_{0.1234}$ | .9123 | .9224 | .9180 | .9573 | .8946 | .9636 | .8972 | .9316 | .9279 | .8658 |
| $R_{0.12345}$ | .9125 | .9246 | .9182 | .9585 | .8960 | .9648 | .9006 | .9395 | .9321 | .8665 |
| $R_{0.12346}$ | .9141 | .9231 | .9180 | .9588 | .8762 | .9666 | .8997 | .9320 | .9360 | .8762 |
| $r_{05.1234}$ | −.0411 | .1450 | .0491 | .1609 | .1111 | .1764 | .1780 | .3354 | .2357 | .0684 |
| $r_{06.1234}$ | .1372 | .1019 | −.0093 | .1269 | .1207 | .2830 | .2482 | .0740 | .2184 | .2687 |

* The following is the key to be used with this table:

0 = Weight
1 = Height
2 = Chest Circumference
3 = Hips
4 = Knee
5 = Sitting Height
6 = Shoulders

## CHAPTER V

# THE SELECTION OF MEASUREMENTS: MEASUREMENTS OF FAT AND SUBCUTANEOUS TISSUE

The research in this field is at present less complete than that in the field of over- and underweight or of breathing capacity. Relatively comprehensive studies have been completed on the upper age groups, but these have not as yet been extended down through the lower age groups. Pending the completion of such studies, the measurements which have evolved from the studies on the older subjects may be applied to the younger children.

The first study in this field which we have been able to find was that of Matiegka (31) who, in 1921, reported his efforts to evaluate the amount of the various elements concerned in the make-up of the body. Matiegka measured the fold of skin and fat with blunt pointed calipers, "with the exertion of a mild pressure just enough to enable the skin fold to slip out of the branches (of the sliding calipers) when the fingers do not hold it any longer." He measured the skin fold on (1) the front of the upper arm above the biceps, (2) on the palmar side of the forearm at the level of the maximum breadth, (3) on the thigh halfway between the inguinal fold and the knee, over the quadriceps muscle, (4) on the calf of the leg at the level of the greatest width, (5) on the thorax, halfway between the nipples and the umbilicus (at the costal margin), and (6) on the abdomen, halfway between the umbilicus and the anterior superior spine of the ilium. These measurements were made with a pressure that had not been standardized, except subjectively, and the size of the fold taken is not stated. Matiegka did not attempt to use this to develop a standard of nutritional status.

In 1929 Franzen (17) proposed three measurements of skin and subcutaneous fat; one was taken on the front of the upper arm, one on the back of the upper arm, and one over the calf. This latter was found to be too adherent to permit of its being used in all cases, and was abandoned. Frazen proposed standards for the ages of ten, eleven, and twelve for these subcutaneous fat measurements. These standards were developed from multiple regression equations computed from measurements of height, width of hips at the trochanters (with pressure), depth and width of chest, and width of shoulders at the acromion. Franzen made a very real contribution in the technique of measuring this skin and subcutaneous fat, in devising calipers for the purpose with springs of constant tension, and in proposing a standard technique.

In the opinion of the present author, however, the proposed standards are based upon faulty assumptions. Franzen's measurements upon which the standards are based include three (chest depth, chest width, and width of hips over the trochanters) which in themselves include fat. It is well known that the measurement over the hips at that level also includes a fat pad that is proportionately thicker than the fat of the other parts of the body. The effect of using measurements which include fat to predict normal fat may be seen in the following hypothetical case.

On page 29 of Franzen's book, one boy's measurements are given. We have chosen this one to illustrate our point, as his fat, according to the computations presented, is about average. Let us suppose that he becomes fatter — fat enough that approximately half a centimeter of fat is added on all sides of his chest (increasing both depth and width by one centimeter), and approximately two centimeters on each side of his hips at the trochanters. The contrasted measurements are shown in the following tabulation, in which the first column contains the figures as given by Franzen and the second as they would be with this amount of fat added. It should be kept in mind that in Franzen's equations the chest measurements are twice one diameter, as the sum of the measurements in inspiration and in expiration is given in each case.

Effect of Increased Fat on Franzen's Prediction of Normal Fat

| Measurement | Original* | As Changed |
|---|---|---|
| Height | 54.5 | 54.5 |
| Hips | 25.9 | 30.0 |
| Chest depth | 31.7 | 36.0 |
| Chest width | 45.9 | 50.0 |
| Shoulders | 30.3 | 30.3 |
| "Normal" amount of fat on front of biceps by Franzen's formula | 27.7 | 36 |

* Height in Franzen's study is given in inches, diameters in centimeters, and fat measurements in an arbitrary scale, which is millimeters plus six.

In other words, it would seem that if bodily measurements which include fat are used for the purpose of computing fat, the results will show that fat children will be fat! If the boy used as an example above were to grow to be fat as has been indicated, his "norm" would have been increased from 27.7 to 36 — while his skeletal build remained the same. This has led us to reject this method of devising standards in favor of the method which will be discussed in the second volume of this series. However, Franzen's splendid pioneer study, undertaken at a time when there was no experience in this field, has opened up the field, standardized the techniques, and should be the stimulus to many other studies which will advance this aspect of the work in nutrition within the next few years.

Three studies (22, 29, 37) have been made in the field of fat and subcutaneous tissue at this Station. Since the method and scope of all three were similar, the findings will be summarized together in this volume, and detailed reports of each study will be presented elsewhere.

For the preliminary trials half a dozen fat subjects, half a dozen thin subjects, and about a dozen fairly average subjects were chosen. Fat measurements were taken on a large number of locations on all parts of the body. Several of these locations were found to be of such a nature that in many individuals the skin was too adherent to the underlying muscle or other tissue to be readily picked up in a double fold for measurement. These locations were rejected, and the experimenters proceeded to collect data upon a large number covering the whole range (an ordinary random sample) of the age group studied. The locations retained for further study by each of the experimenters will be found in Table 15.

The normal weight for each individual was computed from measurements of height, chest girth (corrected for fat), width of hips at the crests of the ilia (corrected for fat), and widths of elbow and knee at the epicondyles. These norms or regression values were then divided into the actual weight and the result multiplied by one hundred to obtain the percentage that the individual's actual weight was of the normal weight, which quotient could be readily interpreted in terms of percentage over and under the normal weight. This percentage of over- and underweight was taken as one criterion of nutritional status. As will be shown in Chapter VI, over- and underweight are more dependent upon muscular development than upon fat in the largest majority of individuals. This means, of course, that the correlation of fat with under- and overweight will be lowered. No attempt was made to hold muscle girth constant as it was felt that while this would raise the correlation of fat and overweight, it would probably not change the relative rank of these correlations and would unnecessarily complicate the study.

In the studies by Marshall and Royce, another criterion was developed. All of the direct fat measurements were summed to obtain a criterion which was termed "total fat." (By direct measurements is meant measurements with the fat calipers directly upon a double fold of skin and subcutaneous tissue. The measurement obtained by subtracting the bi-cristal width of the hips (corrected for fat) from the width of the trochanters without pressure was omitted from this "total fat.") Correlations were obtained between each fat measurement and the total fat measurements, as well as between each fat measurement and over- and underweight. This "total fat" criterion was of limited usefulness, however, because as more and more variables were added in a multiple regression, the results became progressively spuriously higher, owing to the inclusion of these variables in the criterion. It was used primarily for comparing the zero order correlations and for confirming or weakening the evidence presented by the correlations with over- and underweight.

The problem of the measurement of fat for the purpose of evaluating nutritional status is complicated by two facts. First, it is

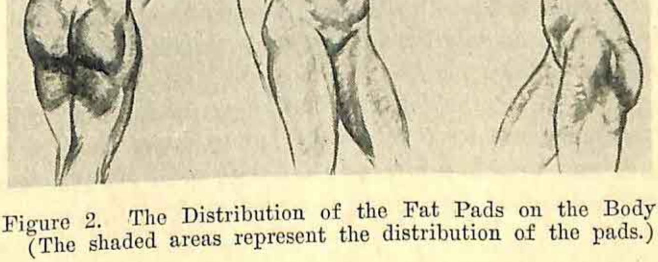

Figure 2. The Distribution of the Fat Pads on the Body
(The shaded areas represent the distribution of the pads.)

possible to measure only the fat immediately beneath the skin. The fat on the omentum and other internal body fat may have a relatively large influence on weight and may be highly correlated with nutritional status, but at the present time it cannot be measured directly. Second, the external fat, namely the fat just under the skin, is not evenly distributed over the surface of the body. There is a tendency for this subcutaneous fat to be deposited in greater amounts in certain locations in what have been termed by anatomists "fat pads." (See Figure 2) One of these is found above and behind the shoulders, just at and below the base of the neck; another is on the back and upper part of the arm, including the large part of the posterior aspect of the deltoid muscle and the upper half of two-thirds of the triceps region. A third is found over the abdomen starting from just above the umbilicus and running down to the pubis and extending outward almost to the vertical level of the anterior superior spines. Another set lies over and above the trochanters. There are two major pads in this group. One runs from almost the height of the umbilicus and extends from the vertical level of the axillary line, running downward and backward over the area of the gluteus maximus and the back part of the gluteus medius. The second lies just below this and runs from about the anterior superior spine downward and diagonally backward to the part of the thigh just below the gluteal fold. This pad lies over the greater trochanter and sometimes extends quite a distance down the outside of the thigh. Another set of pads lies over the inside and outside of the thigh itself. These fat pads are present most noticeably in the postpubescent female. The fat seems to be much more evenly distributed in the prepubescent of either sex. The postpubescent male develops the neck, back of arm, abdominal, and thigh pads more than the hip pads, while the postpubescent female develops all of them, but seems to develop the abdominal pads less and the hip pads more than the male. Even in slender and underweight postpubescent females the X-ray usually shows from 2 to 5 centimeters of fat over the greater trochanter, while in the underweight male the calipers rest practically on the bone.

These facts about the fat distribution made it seem desirable to study postpubescent groups rather than prepubescent groups for the first survey of this problem in order to meet the problem in all its complications, and an endeavor was made to secure measurements of areas with fat pads as well as areas without fat pads. Two types of measurements were taken. The one comprising far the greater number of measurements used the fat calipers developed by the American Child Health Association, which were applied directly to a double fold of skin and subcutaneous tissue picked up by the fingers. The techniques used in this Station for these fat measurements are described in Chapter IX. The second type of fat measurement was applied only to the fat over the trochanters. The fat pads in this location present a rather difficult problem, particularly in the postpubescent female and also in the relatively corpulent male. It is practically impossible to pick up fat over this region or in any place around the gluteal region. Hence, it seemed impracticable to attempt to measure this fat with the fat calipers. Two attempts were made to secure an estimate of this fat accurate enough to increase the multiple correlations with the criteria. The first was to compare the measurements of the width of the hips at the trochanter without pressure with the width at the same place using maximum pressure. The second was to compare the width of the hips at the trochanters without pressure and the width of the hips at the crests of the ilia with pressure and corrected for fat. The former was of little value, but this latter measurement gave excellent results. The zero order correlations with each criterion are seen in Table 15. Further study of these fat measurements was made with partial correlations. Certain of these fat measurements practically duplicated each other so that one added nothing appreciably to the multiple correlation with the criterion if the other was used. This enabled the experimenters to reduce the number of such measurements selected for the final battery.

Several practical demands influenced the selection of the final battery. In the computation of over- and underweight the circumference of the chest and the width of the hips at the crests of the ilia must be corrected for fat. For the purpose of correcting the former it has been found that the measurements we have called "front of chest" and "back of chest" are the best measurements to use. For the correction of hip width the measurement of the fat in the axillary line just above the crest of the left ilium is used. Since these measurements would have to be taken anyhow, it was decided to put them in the battery if they added enough to justify their inclusion.

The width of the trochanters without pressure minus the bi-cristal width of the hips with pressure, corrected for fat (This measurement will hereafter be called the "hip difference."), in both sexes gave a relatively high correlation with the criterion and a correlation that was not partialled out by other measurements. In other words, it apparently measured something different from that measured by the other direct measurements.

The final battery in these studies was reduced to the following two sets of measurements:

1. Front of chest
   Back of chest
   Suprailiac
   Hip difference
2. Front of arm
   Back of arm

To the first we have added the measurement taken halfway between the left nipple and the umbilicus. This adds relatively little to the multiple correlation but has the advantage of being readily picked up in all individuals. Occasionally individuals are found in whom it is very difficult to pick up the fold of skin in the location we have called "chest front." This latter may be estimated very accurately by the curvilinear regression value from the nipple-umbilicus measurement. It will readily be seen that the first battery may be used only in situations where it is possible to remove the subject's clothing, at least to the waist. In situations where this is not possible, the second battery is suggested. This battery represents very much the same thing as that proposed by Franzen and his coworkers. As will be seen in Table 15, the multiple correlation of this battery with the criterion of over- and underweight is decidedly less than that of the first battery. It can be taken, however, on one bare arm and is readily available in all situations, but should be considered a makeshift rather than a fundamentally sound criterion.

The multiple correlations of the most important of these combinations will be found in Table 15. A further attempt to determine the relationship of over and under fat to over- and underweight was made in a study on young adults. The average of four fat measurements (front of arm, back of arm, front of chest, and back of chest) were reduced to deviations of a single skin and fat thickness from the average of all, and the result multiplied by the computed surface area of the body in square centimeters.[10] This

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[10] Computed by Scammon's formula, $394.56\ W^{.575} \times H^{.275}$ (Personal communication from Dr. R. E. Scammon, University of Minnesota)

Table 15

Analysis of Measurements of Skin and Subcutaneous Tissue

| Measurement | Junior High School Boys | Adult Males | | Adult Females | |
|---|---|---|---|---|---|
| | Correlations | | | | |
| | With Over- and Under-weight | With Over- and Under-weight | Total Fat | With Over- and Under-weight | Total Fat |
| I. Measurements on the Trunk | | | | | |
| 1. Chest, front of axilla | .4253 | | | | |
| 2. Chest front | .5025 | .5540 | .8335 | .5770 | .8776 |
| 3. Chest side | .4579 | * | * | .5947 | .9125 |
| 4. Abdomen, midway between nipple and umbilicus | | .5438 | .8676 | .5909 | .9123 |
| 5. Abdomen, side of umbilicus | | .5216 | .8963 | * | * |
| 6. Abdomen, midway between umbilicus and anterior superior spine | | .4828 | .8678 | .5785 | .8942 |
| 7. Scapula, below spine | .5026 | .4998 | .7738 | .5776 | .8658 |
| 8. Chest back | .4678 | .5676 | .8216 | .5988 | .9089 |
| 9. Back low | .4435 | .4956 | .8515 | | |
| 10. Side suprailiac | .5085 | .5608 | .9113 | .6566 | .8930 |
| II. Measurements of the Arms | | | | | |
| 11. Arm front | .4063 | .4652 | .8202 | .6110 | .8399 |
| 12. Arm back | .3898 | .4609 | .8291 | .5646 | .7822 |
| 13. Forearm lateral | | .4526 | .8282 | .5290 | .8083 |
| III. Measurements on Hip and Legs | | | | | |
| 14. Thigh front | * | .5016 | .8410 | .6106 | .8405 |
| 15. Hip difference | | .5226 | .4873 | .7238 | .6116 |

Note: If measurement is left blank, it was not studied for that group. If marked with an asterisk, it was rejected after trial because it was too difficult to secure a satisfactory measurement consistently. The measurements included in this table are only those retained for serious study by at least one of the three students who have worked on the problem.

Table 15 (Continued)

Analysis of Measurements of Skin and Subcutaneous Tissue

| Correlation* | Adult Males | Adult Females |
|---|---|---|
| $R_{0.123}$ | .5976 | .6682 |
| $R_{0.1234}$ | .6545 | .7810 |
| $R_{0.235}$ | .6461 | .6657 |
| $R_{0.2345}$ | .6532 | .7787 |
| $R_{0.34}$ | .6260 | .7686 |
| $R_{0.234}$ | .6518 | .7784 |
| $R_{0.24}$ | .6461 | .7743 |
| $R_{0.12345}$ | .6852 | .7804 |
| $R_{0.67}$ | .4958 | .6368 |
| $R_{8.1234}$ | .9256 | .9614 |
| $R_{8.12345}$ | .9313 | .9656 |
| $R_{8.67}$ | .8830 | .8779 |

* The following key is to be used with the above correlations:

0 = Per cent over- and underweight
1 = Chest front
2 = Chest back
3 = Suprailiac
4 = Hip difference
5 = Abdomen, midway between nipple and umbilicus
6 = Arm front
7 = Arm back
8 = "Total fat"

would roughly approximate the volume of fat over or under the average, so far as subcutaneous fat is concerned. This was correlated with the over- and underweight in kilograms. The results were:

| | |
|---|---|
| Males | r = .3456 |
| Females | r = .4620 |

These results agree surprisingly well with the correlations of per cent over or under fat with per cent over- or underweight with the percentage of over or under muscle held constant:

| | |
|---|---|
| Males | r = .4857 |
| Females | r = .4236 |

This agreement is the more surprising in view of the difficulties of securing an accurate measurement of the actual average of fat over the entire body. (See Chapter V, p. 111)

The next problem to be studied was the determination of norms of fat for the individual. Attacking the problem philosophically, at least two approaches may be made, either of which may be defended logically.

1. The average amount of fat of all healthy persons of a given

age and sex might be considered as the best. It has been stated, as a result of a study of insurance vital statistics (See footnote, Chapter III, p. 51), that the trend to become heavier in middle and old age is not favorable to longevity; yet a multiple regression prediction of fat from skeletal build for each age would undoubtedly indicate that the norm of fat was higher at each succeeding age. Statistically this is true, but physiologically it does not seem to be desirable. Furthermore, it may be argued that much over and under fatness is due to such physiological disturbances as over or under thyroid gland output, or over or under secretion of the posterior lobe of the pituitary gland. These physiological anomalies are deviates from desirability, and where they influence the fat deposits the result cannot be considered as normal, at least physiologically. Hence, if we considered only the average of all healthy persons of a given age and sex, there would be a very large proportion of persons of linear build who would be found to be under fat, and the majority of those of lateral build would be found over the norm. However, the author inclines to this theory, for if a larger proportion of linears are undernourished and a larger percentage of laterals are overnourished, this should not lead to the conclusion that malnourishment is normal or desirable for the linear and fatness is normal for the lateral.

2. The second line of argument is that nature tends to build her own norms, hence the fact that the linears above have less fat and the laterals have more fat is in harmony with other natural conditions. While the argument is not impressive, it might be held that linears are, on the whole, the possessors of a higher basal metabolic rate, and hence need to dissipate heat more freely than do the laterals with their much lower average basal metabolic rate. Hence nature aids the linear to radiate heat more readily by not insulating him with fat, and protects the heat of the lateral by providing the thicker fatty coating.

This second argument is clouded somewhat by the facts of our modern environment. Most children and adults of the social classes measured at this Station eat more and exercise less than they should. The lateral, with his greater digestive and absorptive area, and his tendency to vagotony, tends to become fatter than he should, or than he would were he working at more strenuous physical labor. The linear, on the other hand, with his constant tendency toward sympatheticotony, tends to be more nervously stimulated by the complexity of the environment than he would be in a more primitive or rural type of civilization, and has his digestive functions interfered with — and he adds less fat. In a more physiologically and hygienically normal environment, the lateral would probably be less plump and the linear more so. Hence, this second argument does not seem to be as clear-cut or logically convincing as is the first.

Therefore, two possible standards are proposed. The first is simply the average of fat measurements for the age and sex, and the second is based upon build or type.

Table 16
Beta Weightings for Different Variables to Predict Total Fat

| Age, Years | Height | Elbow | Knee | Hips | Chest Width | Chest Depth | Chest Circumference |
|---|---|---|---|---|---|---|---|
| | | | | Boys | | | |
| 5 | −.5858 | .3865 | .3300 | .3152 | −.1107 | −.0873 | −.1144 |
| 6 | −.1927 | −.0550 | −.0293 | .2064 | −.5415 | −.1085 | .8885 |
| 7 | −.6218 | .2883 | .3074 | −.0064 | −.0832 | .1432 | .2706 |
| 8 | −.3921 | −.0521 | .1996 | .2086 | .0510 | −.0742 | .4712 |
| 9 | −.3306 | −.0978 | .1855 | .3719 | −.0757 | −.0585 | .4306 |
| 10 | .0218 | −.1682 | .1771 | −.0490 | −.2456 | .0541 | .7143 |
| 11 | −.1435 | .0461 | .1778 | .0189 | .0521 | .2531 | .0046 |
| 12 | −.1047 | −.2295 | .5064 | −.0641 | −.1451 | .1093 | .2307 |
| 13 | −.1931 | .0930 | .4371 | −.3230 | .0443 | .3825 | .1423 |
| 14 | −.4755 | −.0634 | .3422 | .1518 | −.1212 | −.0575 | .4774 |
| 15 | −.5164 | −.0886 | .0942 | .4057 | −.1852 | .1153 | .4875 |
| 16 | −.3239 | −.0053 | .3055 | .1096 | .0269 | .1104 | .0764 |
| 17 | −.2999 | .5779 | .0242 | .0740 | −.7260 | −.6572 | 1.3692 |
| | | | | Girls | | | |
| 5 | −.3763 | .1519 | .3000 | .1119 | −.0857 | −.3094 | .6016 |
| 6 | −.3335 | −.0797 | .2130 | .2954 | −.4147 | −.1961 | .9056 |
| 7 | .2093 | .0311 | −.4057 | .3282 | −.9732 | .6295 | .7235 |
| 8 | −.1378 | .1384 | .1120 | .1180 | −.1041 | .1237 | .3599 |
| 9 | −.3504 | .1559 | .0692 | .2016 | −.3324 | −.1230 | .9624 |
| 10 | −.4332 | −.1570 | .1355 | .3317 | −.1989 | .1302 | .6192 |
| 11 | −.5097 | −.1054 | .2659 | .3537 | −.5384 | .1248 | .6809 |
| 12 | −.3342 | −.0452 | .3514 | .3902 | −.3554 | .3192 | .3294 |
| 13 | −.2741 | −.0952 | .2968 | .2663 | −.1589 | .1670 | .3955 |
| 14 | −.2235 | −.1064 | .3658 | .1836 | −.2774 | −.0183 | .6357 |
| 15 | .0273 | .0300 | .3998 | −.1181 | −.1665 | .1830 | .4061 |
| 16 | −.3955 | −.1469 | .3448 | .1435 | −.4510 | .4572 | .6325 |
| 17 | −.2074 | −.1355 | .3499 | .0473 | −.0621 | −.1259 | .4228 |

In attempting to determine norms based on body build, the first step was to select measurements for correlation with "total fat," which is the sum of the six fat measurements in use at this Station. Obviously girths of limbs and measurements of the chest and hips when uncorrected for fat could not be seriously considered, as they contain varying amounts of fat within the measurements themselves. Hence the measurements selected were the skeletal measurements of height, chest dimensions (corrected for fat), hip width (bi-iliac, corrected for fat), and widths of the elbow and knee. To reduce the statistical labor, partial β weightings for each of these measurements with all the others held constant were computed.[11] These are shown in Table 16.

Upon studying these results, it was seen that in general height had a negative weighting. When ranked as to size, the order of

Table 17

The Prediction of Total Fat: Multiple Correlations Between Total Fat and the Combinations of Variables Indicated

| Age, Years | Height and Corrected Chest Girth | Height Corrected Chest Girth, Hips, and Knee | $\frac{\sqrt[3]{\text{Predicted Weight}}}{\text{Height}}$ | $\frac{\text{Corrected Chest Girth}}{\text{Height}}$ |
|---|---|---|---|---|
| | | Males | | |
| 6 | .256 | .331 | .170 | .200 |
| 9 | .319 | .491 | .334 | .201 |
| 12 | .165 | .362 | .154 | .044 |
| 15 | .337 | .457 | .424 | .116 |
| 18 to 20 | .386 | .430 | .428 | .367 |
| | | Females | | |
| 6 | .305 | .491 | .179 | .103 |
| 9 | .538 | .610 | .428 | .393 |
| 12 | .351 | .597 | .421 | .293 |
| 15 | .376 | .554 | .389 | .285 |
| 18 to 20 | .165 | .384 | .287 | .113 |

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[11] In this preliminary computation chest measurements were not corrected for fat, hence the β weightings for chest will be somewhat spuriously large.

importance seemed to be chest circumference, height, knee,[12] and hips. This is the same battery of measurements that is used to predict normal weight. Using chest girth corrected for fat, three different approaches were made to this problem.

First, multiple regressions and multiple correlations were computed to best predict "total fat" from these four variables. This study was limited to the ages of six, nine, twelve, fifteen, and eighteen.

The second approach was to use only chest circumference (corrected for fat) and height to predict total fat, since it has been shown (Chapter II) that this index is an excellent one for designating body type. These measurements were combined both in the index $\frac{\text{Chest Girth}}{\text{Height}}$ and in a multiple regression equation.

The third approach was to use the measurements of height, chest circumference (corrected for fat), width of hips (corrected for fat), and knee in the form of a weight prediction equation, that is, using *predicted weight* in the form of the "corrected ponderal index," or $\frac{\text{Predicted Weight}^{1/3}}{\text{Height}}$. The correlations of these formulae with total fat are seen in Table 17.

It will be seen that in almost every case the multiple regression value of height and chest girth (corrected) gave a higher correlation with total fat than did the index number of chest girth (corrected) divided by height. In most of the age groups tried, the "corrected ponderal index," or the cube root of predicted (or normal) weight divided by height gave a higher correlation with total fat than did the best height-chest combinations. It will be recalled that this normal weight is computed from the variables of height, chest girth (corrected for fat), hip width (corrected for fat), and width of knee. These same four variables, but with different weightings, when used to predict total fat give the highest correlations with total fat, and these are in most cases significantly higher than the correlations with the corrected ponderal index.

If, therefore, it is desired to estimate the deviations in over or under fatness from regression values based upon build, the best and most practicable method would seem to be to compute the norms from the regression equations based on height, chest girth (corrected), hip width (corrected), and width of knee. This, however, involves a separate set of tables and a separate set of computations. The next most effective method would be to use the corrected ponderal index as the basis for norms. Since normal weight will probably be computed, this will be available without further effort. The obtaining of the index is a matter of only a few seconds on the slide rule. As stated above, however, in our opinion the average value for all cases is the more satisfactory norm to use. Both types of norms will be presented in the subsequent publication of standards.

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[12] Chest width was slightly higher than knee in girls, but not when chest girth was included.

The relatively low multiple correlations will perhaps lead some readers to the belief that these norms are of no value. It should be remembered that fat is one of the most variable factors of the human body. It fluctuates with diet, rest, inactivity, general health, and many other factors which have almost no relationship to physique. The norms, therefore, may be both valid and important, even when the correlation between the predicted norm and the actual is relatively low. If the correlations were strikingly high, it would be much more suspicious, and would indicate that what was being predicted was not the norm, but the actual value.

CHAPTER VI

# THE SELECTION OF MEASUREMENTS
(Continued)

## MEASUREMENTS OF LIMB GIRTH

The purpose of measuring limb girths is a two-fold one. As has been shown by Franzen (17), adequate muscular development is one of the most satisfactory indices of general nutritional condition. This is also indicated by strength tests, as shown by the work of Chamberlain and Smiley (10), in which strength, relative to size and age, correlated .64 with medical examination ratings (original work recomputed with triserial "r"). In addition to this, over- and underweight must be evaluated in the light both of fat and of muscular development. The best evaluation of muscle development is undoubtedly the strength test. If such tests are given and adequately administered, muscular measurements are quite unnecessary. Frequently these tests are not considered feasible, and they are very seldom useful below the age of ten. The work done in strength testing has been reported elsewhere and will not be discussed here (26, 27, 36).

The nearest approach to a feasible measurement of muscular strength other than using the dynamometer has been thought to be the girth of the limbs. When the musculature of the limbs is well developed, the muscles of the rest of the body are also well developed because during general muscular activity they are forced to take relatively the same amount of exercise as that undergone by the limbs. In a study of the relation between the girth of the limbs and the strength of the same, when corrected for fat, a correlation of over .90 was obtained with a group of one hundred fourteen-year-old boys (16). This is consistent with the fact, established by Weber (19, p. 42), that the strength of a muscle varies directly with its cross section. It is, of course, obvious that if the measurement is to be primarily of muscular tissue, the places measured should not include viscera or other nonmuscular structures. In addition, the measurements should be as little influenced by fat as possible. These considerations at once rule out measurements of the trunk and leave for consideration only the measurement of the limbs. Of the limbs, girths of the forearm and calf are the least influenced by fat, while the thigh is the most influenced by fat, especially in the postadolescent female. The upper arm is also influenced greatly by fat in the postpubescent and corpulent person in whom fat pads on the back of the arm have developed. It may be pointed out, however, that for practical purposes the overweight person is not the one with whom we are most concerned as to relative malnutrition. Hence the girths of the upper arm and thigh can be used very well indeed with those who are either relatively normal or underweight. We have included the girths of the upper arm, the forearm, the thigh, and the calf, therefore, as measurements for use in estimating the relative muscular development of the individual.

A study of the correlation of the strengths of specific muscle groups to the total strength of the body has been made on data secured from the Battle Creek College of Physical Education[13] which represent a rather extraordinarily well-administered set of tests. The strength tests given at that institution are taken with the Kellogg dynamometer, an instrument which permits the taking of strength tests on comparatively isolated sets of muscles. All tests were administered by an expert and were made on young adults of rather better than average muscular development. Total strength was determined by adding all test results together, unweighted.

The multiple correlation of the combined strengths of the following functional groups of muscles with the total strength of the body were obtained:

| Muscle Groups | Men | Women |
|---|---|---|
| 1. Wrist flexors and wrist extensors (corresponding to muscles enclosed in forearm girth) | .6681 | .6382 |
| 2. Elbow flexors and elbow extensors (corresponding to muscles enclosed in upper arm girth) | .7675 | .6048 |
| 3. Knee flexors and knee extensors | .8466 | .7333 |
| 4. Knee flexors and extensors and thigh adductors (corresponding to muscles enclosed in thigh girth) | .8976 | .8504 |
| 5. Ankle flexors and ankle extensors (corresponding to muscles enclosed in calf girth) | .7856 | .7590 |
| 6. Pectoralis major and shoulder retractors | .8528 | .7582 |
| 7. Latissimus dorsi and pectoralis major | .8635 | .8005 |
| 8. Combined muscle groups of numbers 1, 2, 4, and 5 | .9351 | .9247 |

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[13] These data were made available through the kindness of Mrs. Ivalclare Sprow-Howland, Assistant Professor of Physical Education, Battle Creek College, Battle Creek, Michigan.

It will be seen from the correlations listed above that the muscle groups measured in the girths of the upper arm, forearm, thigh, and calf correlate very highly with the total muscular strength of the whole body. (Groups 6 and 7 cannot be measured by the tape, but they correlate very highly with the other arm strengths.) Further evidence to strengthen this assumption is reported in a study by Rump (38) in which it is found that similarly high correlations were obtained between one strength measurement and the best combination of all others. These tests were made with the Rogers battery of tests (36), and the results were as follows:

| Measurement | Multiple Correlation With All Other Tests Combined |
|---|---|
| Right and left grip | .6280 |
| Knee extensors | .6882 |
| Erector spinae | .6592 |
| Elbow flexors and latissimus group | .9047 |
| Elbow extensors and pectoralis major | .9124 |

The group tested was composed of high school students of the upper three grades. Correlations are uncorrected for attenuation.

If it could be assumed, as was indicated in the work of Faust (16), that, especially in the case of those not overweight, the girth of the limb correlates as highly as .9 with the strength of the muscles enclosed by the tape — and this assumption was strengthened by the work of Weber (19) cited above — then we might conclude that if it were impracticable to test for strength directly (which may well be the case with small children and in school situations where it is impossible to obtain the funds for the purchase of strength testing apparatus), the measurements of the girths of the limbs might be taken to be an excellent substitute, and these girths are, as Franzen has indicated, dependable measures of nutritional status.

Unfortunately, this assumption is not as valid as it was at first thought to be, though the evidence contrary to it is not entirely clear. Two studies that have been made on general strength present evidence which should lead to further investigation in this field.

Strength tests are made by causing the subject to lift or squeeze a dynamometer which registers the total amount of strength exerted. Generally speaking, these tests are compounded of a battery of tests which measure the strength of various groups of muscles, and the results are totaled.

The strength score is presented in two ways: The crude total score — usually spoken of as the "Strength Index" — represents the total absolute strength score, regardless of the size or age of the subject. The second method is to use an index number obtained by dividing the total strength or strength index by the normal strength index for that age and weight. This has been called the "Physical Fitness Index," usually abbreviated as the P. F. I. This represents the strength relative to the norm for the individual.

In this laboratory, two studies have been made of this relative strength (Physical Fitness Index) and the relative limb girths, obtained by dividing the limb girth by the norm for that individual. The composition of these groups has been determined by the subjects for whom the data were available.

The first group studied was composed of college women. This group would present this problem in all of its complexity, for the development of fat pads and the habits of relative idleness that many women fall into after the beginning of the senior high school would be present to a large degree.

The correlations of the Physical Fitness Index and the residuals of muscle girth as determined from the chest size and widths of elbow and knee were as follows:

| Girth | Correlation |
|---|---|
| Upper arm | .124 ± .066 |
| Forearm | .171 ± .066 |
| Thigh | −.009 ± .067 |
| Calf | .193 ± .065 |
| Total (average) | .151 ± .066 |

These very small correlations are discouraging. In the light of the studies on the relationship of muscle strength and girths of the limbs cited above, two explanations present themselves as possibilities.

First, in these postpubescent women the variations in fat are great. None of the limb girths are corrected for fat, for in this case the purpose of the study was to determine the relationship of the girths as found to general bodily strength. It is quite possible that this large variation in the fat explains much of the finding. This is not the whole story, however, for in the further studies[14] of these data relatively small correlations were found in these women between the individual muscle girths (corrected for fat) and the strength. The correlations were much smaller than the corresponding ones in boys.

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[14] These data are taken from the doctor's dissertation of Miss Aileen Carpenter, not yet published. A full account will be made available later.

The second possibility is more difficult to study effectively and has not been attacked as yet. The current physiological literature proposes that when skeletal muscle contracts the individual fibers contract in maximum contractions, but that when movements not involving much strength are undertaken by the muscles only a few of the fibers are thrown into contraction at one time. It has been proposed that the phenomenon, frequently observed but never measured, of a usually weak person suddenly manifesting great strength when hysterical or angry or delirious may be due to the fact that the individual is suddenly enabled to throw almost all of his fibers into contraction at one time, when, under normal conditions, this does not seem to be possible.

If this theory is a sound one, it is quite probable that there are wide individual differences in the ability to throw the muscle fibers into contraction. This would probably be based upon athletic experience, motivation, excitement, skill in taking such tests, and a number of other factors. There may be muscular development without a corresponding degree of muscular functioning. From the standpoint of measuring motor ability, the strength tests in that case would be much the more important. From the standpoint of nutritional status, it may well be that the girths of the limbs may be more important — and there is some considerable evidence adduced in this chapter to show that this is true.

In the study by Faust (16) referred to above, the high correlation between strength and girth of muscle was obtained by correcting for attenuation. The formula used was:

$$r^2_{xy} = \frac{r_{x_1y_2} \cdot r_{x_2y_1}}{r_{x_1x_2} \cdot r_{y_1y_2}}$$

In this formula x = arm strength and y = the girth of the muscle. It will be seen from this formula that the raising of the raw correlations is dependent upon the unreliability of the zero order correlations. The measurement of girth was quite accurate and reliable, but that of the arm strength was not nearly as consistent. Since the tests were taken on different days, this was probably due to the differences in the number of fibers that can be thrown into contraction at one time.

The second study was made on a number of high school boys of the University High School in Iowa City. The ages were from sixteen to nineteen inclusive. These studies were made in two different ways. The first was like that outlined above for the women. One possible shortcoming in this method of study was seen in the procedure of obtaining the Physical Fitness Index.

The Index is obtained from a norm for age and actual weight. In this strength test, two of the tests are (1) the leg lift, in which, in addition to the strength registered on the dynamometer, the individual has to exert enough strength to raise his weight, and (2) the back lift, in which he raises about another quarter of his weight. Hence, the overweight person will be somewhat handicapped in having to lift more weight than that which might be considered "normal for his muscles," while the underweight person will be aided a bit, thus influencing the numerator of the Index. The norm in the denominator is determined in part by the actual weight. In overweight persons, this norm is therefore spuriously large. Overweight is thus penalized both by decreasing the numerator and increasing the denominator of the fraction, while underweight is similarly rewarded.

To endeavor to meet this objection, the following procedure was adopted. To the total strength, one and one-fourth times the actual weight was added. The norm in the denominator was determined from age and normal weight, as determined from our Station standards. We shall call this the "Adjusted Physical Fitness Index." The correlations with the residuals of the limb girths from the normal with both methods are as follows:

| | Physical Fitness Index | |
|---|---|---|
| Girth | Crude | Adjusted |
| Upper arm | −.1390 | .0044 |
| Forearm | −.0189 | .1595 |
| Thigh | −.2989 | −.1354 |
| Calf | −.1586 | .0373 |
| Total (averaged) | −.2294 | −.0171 |

From these correlations, it will be seen that the limb girths are not useful for predicting relative strength, although they are useful for predicting nutritional status in general. Much more study of this area of health and physical status will be required before these problems can be settled satisfactorily.

## RELATIVE CONTRIBUTION OF MEASUREMENTS OF OVER- AND UNDERWEIGHT, OF FAT, AND OF LIMB GIRTH TO THE ESTIMATION OF NUTRITIONAL STATUS

This problem presents difficulties in securing valid criteria of nutritional status against which to evaluate the fat and muscle measurements. Three attempts have been made to solve the problem.

In the first it has been assumed that the percentage of over- or underweight must be used as at least a partially valid criterion of nutritional status. Against this has been correlated the percentage of over and under fat and the percentage of over and under normal muscle girth, averaging all of the fat and all of the muscle girth over and under normal percentages. It is apparent from the multiple correlations that there are other things in addition to these two that affect the under- and overweight. As has been mentioned previously, we have no method of determining the amount of internal fat, or how well it correlates with the amount of external fat, nor do we have the means at this writing of determining the amount of muscle that has not been measured — muscle in other parts of the body.

The results on two groups of eighteen- and nineteen-year-olds are cited as examples. This age, because of the development of the fat pads, presents the most complications of any of the ages studied:

$x_0$ per cent of over- or underweight
$x_1$ per cent of over or under fat
$x_2$ per cent of over or under muscle measured by the tape

| Correlation | Males | Females |
|---|---|---|
| $r_{01}$ | .5543 | .4328 |
| $r_{02}$ | .7438 | .6666 |
| $r_{12}$ | .3342 | .1836 |
| $r_{01.2}$ | .4857 | .4236 |
| $r_{02.1}$ | .7121 | .6625 |
| $R_{0.12}$ | .8116 | .7369 |
| $\beta_{01.2}$ | .3454 | .3208 |
| $\beta_{02.1}$ | .6275 | .6088 |

In studies of a number of younger age groups, from infants to adults, approximately the same relative weightings are found. The $\beta$ weightings cited above are the regression weightings in standard score form and represent the relative contributions of each variable to the criterion variable. It will be seen from these correlations that the over and under muscle estimations are influenced relatively little by the amount of fat. Second, it will be seen that in so far as over- and underweight is a measurement of nutritional status, the relative girth of the limbs is a much better criterion of nutritional status than is the relative amount of fat. The exceedingly low intercorrelations between the over and under muscle and the over and under fat would seem to indicate that the estimation of the relative amount of muscle was influenced but little if any by the amount of subcutaneous fat included within the tape.

## RELATIONSHIP OF LIMB GIRTHS AS DISTINCT FROM FAT TO OVER- AND UNDERWEIGHT

An attempt was made to determine the influence of muscle on under- and overweight, with the influence of fat eliminated. Owing to the fact that adequate fat measurements on the limbs were restricted to the arm, the study was made with the upper limb only. The study was limited to young male adults. The resulting correlations were as follows:

| | |
|---|---|
| $x_0$ | per cent over- or underweight |
| $x_1$ | girth of upper arm |
| $x_2$ | girth of forearm |
| $x_3$ | fat, front of arm |
| $x_4$ | fat, back of arm |
| $x_5$ | fat, front of chest |
| $x_6$ | fat, back of chest |
| $x_7$ | circumference of chest (corrected for fat) |

| | Correlation |
|---|---|
| $r_0(_{1.347})$ | .4935 |
| $r_0(_{1.567})$ | .3998 |
| $r_0(_{1.34567})$ | .4052 |
| $r_{01.7}$ | .5514 |
| $r_0(_{2.347})$ | .3741 |
| $r_0(_{2.567})$ | .2758 |

| | Correlation |
|---|---|
| $r_0(_{2.34567})$ | .2762 |
| $r_{02.7}$ | .4047 |
| $R_{0.12/34567}$ | .5338 |
| $R_{0.3456/127}$ | .3325 |
| $R_{0.12/7}$ | .5706 |
| $R_{0.3456}$ | .4313 |

This type of correlation may be read as follows: $r_0(_{1.347})$ is the correlation between the per cent over- or underweight and the girth of the upper arm with the fat on the front and the back of the arm and the chest girth (corrected for fat) held constant to arm girth, but not to over- and underweight. $R_{0.3456}/_{127}$ is the correlation between over- and underweight and the best weighted combination of variables 3, 4, 5, and 6 (their regression value), but with variables 1, 2, and 7 held constant.

From the correlations listed above, it will be seen that the arm and forearm girths correlate rather respectably with over- and underweight when fat is held constant, and that this correlation is higher than the multiple correlation between over- and underweight and the best weighted combination of all of the fat measurements together, with arm girths held constant. It will be seen, further, that the two arm girths or the upper arm girth alone, even uncorrected for fat, correlate even more highly with over- and underweight. These are always, however, in terms of deviations from their expected values from predictions based upon the chest girths, which, as has been stated, seems to be the one best variable for the prediction of normal muscle girth. Even higher correlations may be secured by using the deviations from the normal as computed from at least one other measurement (usually the width of the elbow or of the knee).

These studies all agree in pointing to the fact that in so far as over- and underweight can be taken as a criterion of physical status — over- and underweight being computed as from a norm for age, sex, and build — muscular development is a more valuable measure of physical status than is fat; but both together predict over- and underweight better than does either one alone. Further, over- and underweight is not perfectly predicted by both even in their best combination. This is probably due to several causes. First, the limited number of measures used in the estimation of fat comprise only a partial sample. They measure only the subcutaneous fat, and the fat, even under the skin, is not at all evenly distributed over the whole body. Second, the muscle girths are those of the limbs alone and neglect trunk muscles entirely. Third, both muscle girth norms and norms for weight are computed from a smaller number of variables than would be optimum for exact scientific purposes. This has been done, however, in the interests of practicality. It is thought to be more important to produce standards that can readily be used than it is to produce standards that will be more meticulously accurate but be too complicated for the teacher, physician, and nurse.

A third study was made on two small groups of preschool children (males, seventeen cases; females, fifteen cases). Careful medical examinations were made on these children by a pediatrician of experience. This physician had previously experimented with methods of grading the children semiobjectively in both the medical examination and in his estimate of nutritional status. The blank used for the marking of the various items of the ratings on nutritional status is shown in the following tabulation:

| Correlations of Doctor's Estimate of General Nutritional Status (Preschool Ages) With: | Measurement* | Males | Females |
|---|---|---|---|
| Over- or underweight | a | .65 | .66 |
| | b | | .71 |
| | c | .76 | .44 |
| Over or under fat | a | .54 | .46 |
| | b | .36 | .58 |
| | c | .56 | .61 |
| Over or under limb girths | a | .34 | .64 |
| | b | | .54 |
| | c | .36 | .51 |
| Weight, fat, and limb girths** | a | .69 | .73 |
| | b | | .81 |
| | c | .82 | .61 |

* a, b, and c represent measurements on different dates, spaced about four months apart.

** Multiple correlations

After having filled this out, the physician studied the ratings of each item, took into account the medical findings of the physical diagnosis, and then assigned a "total nutritional score" on the basis of these findings. The children were graded in five categories ranging from excellent to very poor.

After the children had been measured by the anthropometrists of the Station, their over- and underweight indices, the over and under fat, and the over and under limb girths were computed (in terms of percentages of the norm), and the results were correlated against the physician's ratings. The results are shown in the tabulation below.

| Correlations of Doctor's Subjective Ratings of Specific Variables (Preschool Ages) with | Males | Females |
|---|---|---|
| Objective Measurements of the Same Variable | | |
| Fat | .64 | .44 |
| Limb Girths | .47 | .51 |
| Doctor's estimate of fat and doctor's estimate of limb size | .40 | .75 |
| Doctor's estimate of fat and build* | −.07 | −.49 |
| Doctor's estimate of limb girth and build | −.10 | −.51 |

*Build computed from $\frac{\text{Corrected Chest Girth}}{\text{Height}}$

It must be clearly understood that this represents correlations between careful estimates and objective measurements. Low correlations are as apt to be due to lack of validity of the ratings of the physician as to lack of validity of the measurements. Franzen (17) found that the average reliability of two physicians rating the same children was not higher than .60. It is our belief that the validity of the ratings by the physician participating in this study is relatively high. There is evidence that he was not influenced by body build into overestimating the nutritional status of stocky children and underestimating that of slender ones. There was some evidence that he was more influenced by muscular development than by the amount of fat on the child. But on the whole, the internal evidence of the correlations tried with this small group would lead us to believe that the validity of his estimates would be at least as high as .7 or .8. Much of this opinion is based upon intimate knowledge of the conditions of the examinations and cannot be supported by objective statistical findings.

If this is true, and if the reliability of the physician's estimates is in the neighborhood of .80, then the correlations between the objective measurements of physical status (over- and underweight, over and under fat, and over and under muscular development) will be lower than would be represented by the facts. The "true correlations" would be better represented by correlations corrected for attenuation, which would be approximately 30 per cent higher than those in the table.

There is no reason to believe that there is any larger validity of the physician's estimates than there is in the objective measurements. Hence, these correlations may be thought to be validations of the doctor's estimates as much as validations of the measurements. Thus the high zero order and multiple correlations obtained with the physician's ratings, even though obtained on such a small sample, is indicative of the very high validity of both doctor's ratings and of the anthropometric standards.

At the present, no other studies of these standards in comparison with medical estimates have been made. Such studies should be made as soon as possible, and on a comprehensive scale. Pending such results, those presented here may be cited to indicate the probability that these indices of over- and underweight and the relative amounts of fat and muscle have a high degree of validity as measurements of the physical status of the individual.

## VARIABLES FROM WHICH TO PREDICT NORMAL LIMB GIRTH

There are at least three possible ways in which this problem might be attacked:

1. We might correct each limb measurement for fat by adding or subtracting 2 pi times the difference between the average fat thickness on that individual's limb and the average of the homogeneous group. This corrected measurement might then be predicted from corrected skeletal measurements as is done in the prediction of normal weight.
2. The limb might be measured as a whole, fat and all, and then compared with standards computed from other uncorrected measurements.
3. The limb might be measured as a whole, fat and all, and then compared with standards computed from uncorrected measurements with certain fat measurements added in the prediction equation.

The first of these three possibilities does not seem to be practicable. As we have seen in Chapter V, the fat over the lower limbs is usually too adherent to be readily measured. The assumption which underlies the second possibility is that the amount of fat over the limbs is proportionate to that over the parts used as criterion measurements for predicting the girth of the limbs. This is not necessarily true and is most certainly not true in the prediction of the girth of the thigh in postadolescent females, where much of the thigh girth is dependent upon the fat pads just below the hips. Certainly the skeletal girths should not be corrected for fat in the prediction of the limb girths, as this would simply turn the measurement into one which was primarily a measurement of fat. Therefore, we eliminated the first approach and experimented statistically with the remaining two.

In attempting to predict the limb girths, the variables of height, chest girth, and widths of hips, elbow, and knee were tried. The chest girth was selected in preference to depth and breadth because of the fact that the zero order correlations of chest girth with each of the limb girths were decidedly larger than those of either depth or breadth. In all ages, height immediately partialled out, and in almost all ages, hip width was eliminated when chest girth and either elbow or knee were held constant. The computations were made by laboriously but systematically trying one combination after another for each group. The details of this would be both endless and boring if presented in their entirety. We shall therefore present only the results, which are seen in Tables 18 to 20.

Table 18
Highest Zero Order Correlation with Upper Arm Girth, Forearm Girth, Thigh Girth, and Calf Girth

| Age, Years | Variables | Male | Variables | Female |
|---|---|---|---|---|
| | | Upper Arm Girth | | |
| 4 | Elbow | .5917 | Chest Circumference | .7299 |
| | Chest Circumference | .4692 | | |
| 5 | Elbow | .6178 | Chest Circumference | .7776 |
| | Chest Circumference | .6077 | | |
| 6 | Chest Circumference | .7297 | Chest Circumference | .7402 |
| 7 | Chest Circumference | .6854 | Chest Circumference | .8253 |
| 8 | Chest Circumference | .7350 | Chest Circumference | .7621 |
| 9 | Chest Circumference | .7300 | Chest Circumference | .8392 |
| 10 | Chest Circumference | .7796 | Chest Circumference | .7716 |
| 11 | Chest Circumference | .6831 | Chest Depth | .7180 |
| | | | Chest Circumference | .7033 |
| 12 | Chest Circumference | .7821 | Chest Circumference | .7508 |
| 13 | Chest Circumference | .8439 | Chest Circumference | .7351 |
| 14 | Chest Circumference | .8281 | Chest Circumference | .7698 |
| 15 | Chest Circumference | .8314 | Chest Depth | .7020 |
| | | | Chest Circumference | .6727 |
| 16 | Chest Circumference | .7450 | Chest Circumference | .6177 |
| 17 | Chest Circumference | .7838 | Chest Circumference | .5307 |
| 18 | Chest Circumference | .7451 | Chest Circumference | .7337 |
| | | Forearm Girth | | |
| 4 | Elbow | .7487 | Chest Circumference | .8057 |
| | Chest Circumference | .6048 | | |
| 5 | Elbow | .7027 | Chest Circumference | .7672 |
| | Chest Circumference | .6503 | | |
| 6 | Chest Circumference | .7613 | Chest Circumference | .7723 |
| 7 | Chest Circumference | .7470 | Chest Circumference | .7725 |
| 8 | Chest Circumference | .7780 | Elbow | .7945 |
| | | | Chest Circumference | .7547 |
| 9 | Chest Circumference | .6743 | Chest Circumference | .7979 |
| 10 | Chest Circumference | .7827 | Chest Circumference | .7913 |
| 11 | Knee | .7272 | Chest Depth | .7332 |
| | Chest Circumference | .7220 | Chest Circumference | .7283 |
| 12 | Chest Circumference | .7881 | Chest Circumference | .7868 |
| 13 | Chest Circumference | .8830 | Elbow | .7726 |
| | | | Chest Circumference | .6975 |

Table 18 (Continued)

Highest Zero Order Correlation with Upper Arm Girth, Forearm Girth, Thigh Girth, and Calf Girth

| Age, Years | Variables | Male | Variables | Female |
|---|---|---|---|---|
| | | Forearm Girth | | |
| 14 | Chest Circumference | .8289 | Elbow<br>Chest Circumference | .7323<br>.6535 |
| 15 | Chest Circumference | .8131 | Elbow<br>Chest Circumference | .6094<br>.5603 |
| 16 | Chest Circumference | .7460 | Chest Circumference | .5439 |
| 17 | Chest Circumference | .7591 | Chest Width<br>Chest Circumference | .4295<br>.3276 |
| 18 | Chest Circumference | .6729 | Chest Circumference | .6932 |
| | | Thigh Girth | | |
| 4 | Chest Circumference | .6164 | Chest Circumference | .8128 |
| 5 | Knee<br>Chest Circumference | .7251<br>.6887 | Chest Circumference | .7974 |
| 6 | Chest Circumference | .7526 | Chest Circumference | .7696 |
| 7 | Chest Circumference | .7133 | Chest Circumference | .7847 |
| 8 | Chest Circumference | .7388 | Chest Circumference | .8241 |
| 9 | Chest Circumference | .7687 | Chest Circumference | .8100 |
| 10 | Chest Circumference | .8404 | Chest Circumference | .7617 |
| 11 | Chest Circumference | .7362 | Chest Circumference | .7910 |
| 12 | Chest Circumference | .7917 | Chest Circumference | .7799 |
| 13 | Chest Circumference | .8600 | Hips<br>Chest Circumference | .7227<br>.6697 |
| 14 | Chest Circumference | .8149 | Chest Circumference | .6994 |
| 15 | Chest Circumference | .8188 | Chest Depth<br>Chest Circumference | .6701<br>.5696 |
| 16 | Chest Circumference | .7765 | Chest Circumference | .5676 |
| 17 | Chest Circumference | .8275 | Chest Width<br>Chest Circumference | .6618<br>.5595 |
| 18 | Chest Circumference | .7314 | Chest Circumference | .7255 |
| | | Calf Girth | | |
| 4 | Elbow<br>Chest Circumference | .8044<br>.4976 | Elbow<br>Chest Circumference | .7228<br>.7116 |
| 5 | Chest Circumference | .7069 | Chest Circumference | .7987 |
| 6 | Chest Circumference | .7788 | Chest Circumference | .8309 |
| 7 | Knee<br>Chest Circumference | .6617<br>.6478 | Chest Circumference | .8288 |
| 8 | Chest Circumference | .7477 | Chest Circumference | .7825 |
| 9 | Chest Circumference | .6495 | Chest Circumference | .7041 |

Table 18 (Continued)

Highest Zero Order Correlation with Upper Arm Girth, Forearm Girth, Thigh Girth, and Calf Girth

| Age, Years | Variables | Male | Variables | Female |
|---|---|---|---|---|
| | | Calf Girth | | |
| 10 | Chest Circumference | .8073 | Chest Circumference | .7251 |
| 11 | Knee | .6894 | Chest Circumference | .7309 |
| | Chest Circumference | .6885 | | |
| 12 | Knee | .7899 | Chest Circumference | .7234 |
| | Chest Circumference | .7594 | | |
| 13 | Chest Circumference | .8423 | Knee | .7267 |
| | | | Chest Circumference | .6635 |
| 14 | Chest Circumference | .8039 | Chest Circumference | .6402 |
| 15 | Knee | .7899 | Knee | .6714 |
| | Chest Circumference | .7394 | Chest Circumference | .4870 |
| 16 | Chest Circumference | .6753 | Knee | .6437 |
| | | | Chest Circumference | .4722 |
| 17 | Knee | .6853 | Chest Width | .5799 |
| | Chest Circumference | .6335 | Chest Circumference | .4423 |
| 18 | Chest Circumference | .5608 | Knee | .6465 |
| | | | Chest Circumference | .5787 |

It will be seen that in almost all ages chest girth is the one best measurement for the prediction of all of the muscle girths. Where two measurements are used, in most instances it will be chest girth and elbow width for the prediction of the girths of the upper limbs and chest girth and knee width for the prediction of the girths of the lower limbs. Where there are exceptions to this rule, it will be seen that these values are very close, usually within one probable error of the multiple correlation. The third set of measurements includes a fat measurement. The relative values of these may be seen by comparing their multiple correlations.

The correlations with the three skeletal variables were also computed. The addition of a third variable very seldom increased the multiple correlation more than .01. When the best two were combined with the best fat measurement, the multiple correlation was frequently increased appreciably (from .04 to .10), but the influence was not at all consistent, and the "best" fat variable seemed to have no logical relationship to the girth measured, as for instance, the chest fats might be much superior to the arm fats for predicting arm girth. We have therefore decided to use only skeletal measurements as being safer guides to relative nutritional status.

Table 19

Multiple Correlations of the Best Two Variables for Predicting Upper Arm Girth and for Predicting Forearm Girth

| Age, Years | Variables | Male | Variables | Female |
|---|---|---|---|---|
| | | Upper Arm Girth | | |
| 4 | Chest Circumference and Elbow | .6122 | Chest Circumference and Elbow | .7557 |
| 5 | Chest Circumference and Elbow | .6959 | Chest Circumference and Elbow | .8122 |
| 6 | Chest Circumference and Elbow | .7612 | Chest Circumference and Elbow | .7782 |
| 7 | Chest Circumference and Elbow | .7408 | Chest Circumference and Elbow | .8412 |
| 8 | Chest Circumference and Elbow | .7802 | Chest Circumference and Elbow | .8045 |
| 9 | Chest Circumference and Elbow | .7965 | Chest Circumference and Elbow | .8452 |
| 10 | Chest Circumference and Elbow | .8111 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .7797<br>.7735 |
| 11 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .7409<br>.7237 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .7360<br>.7145 |
| 12 | Chest Circumference and Elbow | .8218 | Chest Circumference and Elbow | .7698 |
| 13 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .8630<br>.8584 | Chest Circumference and Elbow | .7924 |
| 14 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .8373<br>.8346 | Chest Circumference and Elbow | .8331 |
| 15 | Chest Circumference and Elbow | .8476 | Chest Circumference and Elbow | .7137 |
| 16 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .7760<br>.7637 | Chest Circumference and Elbow | .6534 |
| 17 | Chest Circumference and Elbow | .8305 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .6043<br>.5447 |
| 18 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .7546<br>.7527 | Chest Circumference and Knee | .7686 |

Table 19 (Continued)
Multiple Correlations of the Best Two Variables for Predicting Upper Arm Girth and for Predicting Forearm Girth

| Age, Years | Variables | Male | Variables | Female |
|---|---|---|---|---|
| | | Forearm Girth | | |
| 4 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .8072<br>.7783 | Chest Circumference and Elbow | .8579 |
| 5 | Chest Circumference and Elbow | .7702 | Chest Circumference and Elbow | .8204 |
| 6 | Chest Circumference and Elbow | .8338 | Chest Circumference and Elbow | .8313 |
| 7 | Chest Circumference and Elbow | .8263 | Chest Circumference and Elbow | .8435 |
| 8 | Chest Circumference and Elbow | .8619 | Chest Circumference and Elbow | .8558 |
| 9 | Chest Circumference and Elbow | .7881 | Chest Circumference and Elbow | .8341 |
| 10 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .8389<br>.8329 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .8294<br>.8219 |
| 11 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .8084<br>.7985 | Chest Circumference and Elbow | .8190 |
| 12 | Chest Circumference and Elbow | .8357 | Chest Circumference and Elbow | .8453 |
| 13 | Chest Circumference and Elbow | .8980 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .8340<br>.8294 |
| 14 | Chest Circumference and Elbow | .8821 | Chest Circumference and Elbow | .8008 |
| 15 | Chest Circumference and Elbow | .8853 | Chest Circumference and Elbow | .6915 |
| 16 | Chest Circumference and Elbow | .8226 | Chest Circumference and Elbow | .6869 |
| 17 | Chest Circumference and Elbow | .8430 | Chest Circumference and Knee<br>Chest Circumference and Elbow | .4710<br>.4661 |
| 18 | Chest Circumference and Elbow | .7290 | Chest Circumference and Elbow | .7834 |

Table 20

Multiple Correlations of the Best Two Variables with Thigh Girth and with Calf Girth

| Age, Years | Variables | Male | Variables | Female |
|---|---|---|---|---|
| | | Thigh Girth | | |
| 4 | Chest Circumference and Knee | .7009 | Chest Circumference and Knee | .8374 |
| 5 | Chest Circumference and Knee | .7706 | Chest Circumference and Knee | .8154 |
| 6 | Chest Circumference and Knee | .7754 | Chest Circumference and Hips<br>Chest Circumference and Knee | .7865<br>.7762 |
| 7 | Chest Circumference and Knee | .7627 | Chest Circumference and Hips<br>Chest Circumference and Knee | .8116<br>.8081 |
| 8 | Chest Circumference and Hips<br>Chest Circumference and Knee | .7667<br>.7569 | Chest Circumference and Knee | .8610 |
| 9 | Chest Circumference and Elbow<br>Chest Circumference and Knee | .8165<br>.8019 | Chest Circumference and Knee | .8274 |
| 10 | Chest Circumference and Knee | .8497 | Chest Circumference and Knee | .7958 |
| 11 | Chest Circumference and Knee | .7849 | Chest Circumference and Knee | .8303 |
| 12 | Chest Circumference and Knee | .8269 | Chest Circumference and Knee | .8304 |
| 13 | Chest Circumference and Knee | .8916 | Chest Circumference and Knee | .7801 |
| 14 | Chest Circumference and Knee | .8471 | Chest Circumference and Knee | .8186 |
| 15 | Chest Circumference and Knee | .8534 | Chest Circumference and Knee | .7664 |
| 16 | Chest Circumference and Knee | .8063 | Chest Circumference and Knee | .7839 |
| 17 | Chest Circumference and Knee | .8686 | Chest Circumference and Knee | .7302 |
| 18 | Chest Circumference and Knee | .7548 | Chest Circumference and Knee | .7892 |

Table 20 (Continued)
Multiple Correlations of the Best Two Variables with Thigh Girth and with Calf Girth

| Age, Years | Variables | Male | Variables | Female |
|---|---|---|---|---|
| | | Calf Girth | | |
| 4 | Elbow and Knee<br>Chest Circumference and Knee | .8306<br>.6346 | Chest Circumference and Knee | .7282 |
| 5 | Chest Circumference and Knee | .7572 | Chest Circumference and Knee | .8330 |
| 6 | Chest Circumference and Knee | .8129 | Chest Circumference and Knee | .8608 |
| 7 | Chest Circumference and Knee | .7382 | Chest Circumference and Knee | .8558 |
| 8 | Chest Circumference and Hips<br>Chest Circumference and Knee | .7899<br>.7689 | Chest Circumference and Knee | .8264 |
| 9 | Chest Circumference and Knee | .7169 | Chest Circumference and Knee | .7199 |
| 10 | Chest Circumference and Knee | .8418 | Chest Circumference and Knee | .7834 |
| 11 | Chest Circumference and Knee | .7686 | Chest Circumference and Knee | .8147 |
| 12 | Chest Circumference and Knee | .8353 | Chest Circumference and Knee | .8228 |
| 13 | Chest Circumference and Knee | .8776 | Chest Circumference and Knee | .7986 |
| 14 | Chest Circumference and Knee | .8598 | Chest Circumference and Knee | .7347 |
| 15 | Chest Circumference and Knee | .8349 | Chest Circumference and Knee | .7296 |
| 16 | Chest Circumference and Knee | .7465 | Chest Circumference and Knee | .7429 |
| 17 | Chest Circumference and Knee | .7265 | Chest Circumference and Knee | .6317 |
| 18 | Chest Circumference and Knee | .6113 | Chest Circumference and Knee | .6961 |

## CHAPTER VII

# BREATHING CAPACITY

By breathing capacity is meant the measured amount of air that an individual can breathe out by forced exhalation following as full an inhalation as it is possible for him to take. This has also been called in the literature "lung capacity," and "vital capacity." The first term, lung capacity, seems to us a misnomer because this measurement does not determine the capacity of the lungs, for after the complete exhalation there is still left the residual air which cannot be exhaled. The term "vital capacity" is quite meaningless and misleading and is based upon questionable assumptions. What is really meant is the amount of air that can be breathed out; hence we have selected for use the term adopted by Dr. Bird T. Baldwin, first director of the Iowa Child Welfare Research Station, the "breathing capacity of the lungs."[15]

The breathing capacity has long been used as one measure of physical status. The validity of the crude measurement as a measure of physical fitness, however, has not been very well established. At the present time the use of breathing capacity as a valid and effective measurement of physical status partakes as much of the nature of a problem as of that of a determined standard.

Attempts have been made to use breathing capacity for the following purposes:

1. To measure the relative physical robusticity. The fact that outdoor workers and athletes have a larger average breathing capacity than do sedentary workers and nonathletes has been thought to be of significance.

2. To indicate the presence of potential or actual disease: for this purpose a subnormal standard has been proposed. All cases falling below that standard are classed as medically suspicious (Campbell (8), Myers (34), Turner (43)). The use of breathing capacity as an indication of relative recuperation from certain diseases has also been substantiated (McCloy (25)).

3. To measure relative physical adequacy. This differs from the first use in that it attempts to measure not active physical perform-

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[15] The history of the studies in vital capacity and of the uses of the measurements of vital capacity can be found in Meyers, *Vital Capacity of the Lungs* (34).

ance ability or potentiality but exuberance or excesses of potential health. It is the opposite of using breathing capacity as a predictor of actual or potential diseases (Turner (43)).

To utilize this measurement for either of the purposes stated above, several important considerations must be kept in mind.

1. The measurement must be accurate. It is at this point that much of the disappointment in the use of breathing capacity has centered. The necessary precautions for insuring accuracy are discussed in Chapter IX.

2. The standard or normal breathing capacity should be one that is fair to the individual. The various studies in this field have seemed to indicate that a weighted combination of age, height, and weight is superior to any other simple and practicable combination of measurements. The standards for computing normal breathing capacity have been presented in another Station publication (21).

Various authors have proposed the surface area of the body (as computed from height and weight by the DuBois formula (15)) as a basis for estimating normal breathing capacity. Studies including this variable have shown that it has no advantages over other combinations of height and weight and is based on *a priori* assumptions that have not been validated.[16]

Where the normal weight of the individual is available (as computed from skeletal measurements after the method suggested in Chapter III), this should be substituted for weight in all formulae for computing breathing capacity. The reason for this is that the normal weight gives a measurement of the body as it should be, for which size of body the lungs should be adapted. Additional fat piled up on the outside does not in any way affect the size of the thoracic cavity. In cases of obesity, the norm for lung capacity as predicted from actual weight will be far too high. On the other hand, when the norm is predicted from weight that is decidedly below standard, the result is too low and is apt to give a spurious confidence in the physiological adequacy of a subnormal breathing capacity.[17]

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[16] This assumption is that the breathing capacity should be perfectly correlated with the surface area of the body because of the belief that the metabolism of the body is almost perfectly correlated with the surface area. This belief is based upon the assumption that the metabolic rate is determined largely by the amount of heat radiated by the body, which is in turn determined by the amount of area exposed to the air. There is very little factual evidence to support this belief other than that there is a fairly high correlation between surface area and basal metabolism, as there is between surface area and breathing capacity. Benedict and Carpenter in *The Metabolism and Energy Transformations of Healthy Man During Rest* (5) have shown higher correlations with multiple regression weightings of height and weight and metabolism than they found between surface area and metabolism. Kelly (21) has found the same to be true for breathing capacity.

The multiple correlations obtained from correlating breathing capacity from height and normal weight as contrasted with height and actual weight have been obtained for only three age groups of males and females. The correlations obtained are as follows:

| Age, Group | Height and Actual Weight | Height and Normal Weight |
|---|---|---|
| Twelve-year-old males | .761 | .791 |
| Twelve-year-old females | .746 | .770 |
| Fifteen-year-old males | .861 | .858 |
| Fifteen-year-old females | .546 | .556 |
| Eighteen-year-old males | .599 | .638 |
| Eighteen-year-old females | .452 | .458 |

Various attempts have been made to ascertain whether or not other measurements might be added to those of age, height, and weight for the purpose of more accurately predicting breathing capacity. For this purpose multiple correlations were computed between breathing capacity and various multiple regression weightings of combinations of height, weight, chest girth, hip width, widths of elbow and shoulder, and in some other studies done elsewhere than in this Station, with a number of other measurements as well. The results have been somewhat conflicting, but, in general, have not been of such a nature as to warrant adding any other measures than height and weight to the formula for computing breathing capacity for any one age. Detailed results on some of these studies are presented in Table 21 and in the following tabulation:

Multiple Correlations of Breathing Capacity and Combinations of Other Variables (From "fit" adults of the British army air force*)

| Breathing capacity and: | |
|---|---|
| Height and weight | .6222 |
| Height and chest girth | .6246 |
| Height and shoulder width | .6139 |
| Height, chest girth, and weight | .6283 |
| Height, shoulder width, and weight | .6367 |
| Height, shoulder width, and chest girth | .6392 |
| Height, shoulder width, chest girth, and weight | .6423 |

* Cripps, Greenwood, and Newbold (12)

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[17] If it is desired to compute normal breathing capacity from age, height, and weight without computing the normal weight, the best thing to do is to estimate as nearly as possible from the actual weight and the appearance of the individual what his normal weight should be. This, of course, will be important only in the two extremes of over- and underweight, and the work of measurement and computation necessary to obtain normal weight would not be justified for the purpose of computing normal breathing capacity alone.

Table 21

Multiple Correlations of Breathing Capacity and Combinations of Other Variables

| Correlation* | Males | | | | Females | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 Years | 12 Years | 14 Years | 18 to 20 Years | 10 Years | 12 Years | 13 Years | 18 to 20 Years |
| $R_{0.123456}$ | .687 | .870 | .816 | .666 | .765 | .747 | .728 | .513 |
| $R_{0.12345}$ | .687 | .867 | .815 | .661 | .760 | .746 | .726 | .510 |
| $R_{0.1234}$ | .678 | .844 | .814 | .661 | .760 | .746 | .724 | .491 |
| $R_{0.123}$ | .669 | .839 | .801 | .660 | .759 | .746 | .724 | .480 |
| $R_{0.12}$ | .659 | .824 | .800 | .599 | .722 | .743 | .722 | .452 |
| $r_{02}$ | .653 | .799 | .783 | .506 | .697 | .719 | .692 | .388 |
| $r_{01}$ | | | | .521 | | | | .378 |
| $R_{0.23}$ | | | | .540 | | | | .423 |

* The following is the key to be used with this table:

$x_0$ = Breathing Capacity
$x_1$ = Weight
$x_2$ = Height
$x_3$ = Chest Girth
$x_4$ = Shoulder Width
$x_5$ = Hip Width
$x_6$ = Width of Elbow

In all but the 18 to 20 year old men, height correlated higher than any single variable. In this group, weight and chest girth were slightly higher; but the weight-height multiple correlation was larger than that of weight and chest.

It should be pointed out that almost all of the measurements used for the prediction of breathing capacity are the standard anthropometric measurements of the type that are usually thought of as skeletal measurements and have not been chosen particularly for their probable adequacy. It should be clear that the breathing capacity is not equivalent to the volume of the thoracic cavity. In addition to the fact that this volume is occupied by varying amounts of other visceral organs, the amount of air that can be exhaled in a forced exhalation is probably as much dependent upon the contractability of the thorax as upon its size. This contractability may as well be due to the relative slant of the ribs from the spine as to its muscular and ligamentous elasticity. Further attempts to measure the size of the thorax have so far omitted all reference to vertical measurements of the thorax itself. It should not surprise us, therefore, that the correlation between the prediction equations and breathing capacity is relatively low. To date, no really adequate study of this field has been presented.

In view of the results presented in the table, it is felt that since height and weight, when properly combined in a regression formula for each age, predict the breathing capacity with an accuracy that differs but slightly from that obtained when other anthropometric measurements are added to the formula, the addition of such other measurements would not be justified from an administrative point of view. Until further researches which take into account other kinds of variables demonstrate that more complicated procedures present improved methods of computing the normal breathing capacity, it is recommended that the norm be computed from height and normal weight, or where normal weight is not available, from height and approximated normal weight, or from height and actual weight. Standards for this are found in Kelly's study.

## CHAPTER VIII

# MEASUREMENTS SELECTED FOR EVALUATING PHYSICAL STATUS

A summary of the findings of the preceding chapters is in order for the purpose of making clear the measurements indicated for the evaluating of physical status from anthropometric methods alone.[18]

I. Measurements for Determining Normal Weight and the Percentage Deviation from Normal Weight
   1. Weight
   2. Total height
   3. Chest circumference, measured at the level of the base of the xiphoid cartilage (corrected for deviations from the average of fat and subcutaneous tissue)
   4. Width of the hips at the crests of the ilia (corrected for deviations from the average amount of fat and subcutaneous tissue)
   5. Width of the knee at the epicondyles

II. Measurements for Determining the Relative Amount of Subcutaneous Fat on the Body and for the Secondary Purpose of "Correcting" Chest Circumference and Hip Width
   1. Arm front
   2. Arm back

      These two measurements are to be taken only if the following measurements may not be taken because the subjects cannot be measured without clothing.

   3. Chest front
   4. Chest back

      These two measurements are used to correct chest girth for deviations from the average amount of fat.

   5. Supra-iliac

      This measurement is used to correct hip width for fat for deviations from the average.

   6. Abdominal (midway between nipple and umbilicus)
   7. Hip difference

      This is not taken with the skin calipers, but is the difference between the hip width at the trochanters, taken without pressure, and the hip width at the crests of the ilia, corrected for fat.

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[18] Details of the techniques used for the taking of these measurements are given in Chapter IX.

III. Measurements for the Purpose of Determining the Actual Limb Girths and Norms for Limb Girths (for Determining Muscular Development)
  1. Girth of upper arm
  2. Girth of forearm
  3. Girth of thigh
  4. Girth of calf
    These measurements are used to measure the actual size of the limb at the point where the greatest amount of muscle is included within the tape.
  5. Width of elbow at the epicondyles of the humerus
  6. Width of knee at the epicondyles of the femur
  7. Girth of chest at the level of the xiphoid cartilage
    These last three measurements are used for the purpose of determining normal or standard limb girth.

IV. Measurement of the Lungs
  1. The breathing capacity, or the total amount of air which can be exhaled into a spirometer after a maximum inhalation

For the purpose of determining the standard breathing capacity the height and weight seem at the present time to be the most practical measurements to use. As is indicated in Chapter VII, however, the chest circumference in some age groups adds definitely to the predictive value of height and weight. These measurements are all included in the ones used for determining what is normal or standard weight.

V. Supplementary Measurements
  1. Depth of chest at the level of the xiphoid cartilage
  2. Width of chest at the level of the xiphoid cartilage

These measurements are useful in a very small number of cases for the purpose of "correcting" the chest girth in such persons as have exceedingly flat or exceedingly barrel shaped chests. The measurements are of very limited usefulness and may well be omitted in routine measurements. (See Chapter IV)

VI. Indices of Body Build
  1. $\frac{\text{Weight}^{1/3}}{\text{Height}}$
  2. $\frac{\text{Chest Circumference}}{\text{Height}}$

In the light of our present researches from the standpoint of evaluating physical status, these measurements seem to be all that are really useful, at least in view of the limitations imposed by the demand for economy in time in almost all school and other institutional situations. Detailed standards for applying these measurements will be published in Volume II of this series.

## CHAPTER IX

# LANDMARKS AND TECHNIQUES OF MEASUREMENT USED IN THESE STUDIES

Techniques of measurement in physical anthropology differ widely throughout the world in spite of the number of attempts made to standardize them. In 1912 a commission of the Fourteenth International Congress of Prehistoric Anthropology and Archaeology presented a report which was adopted by the Congress and termed *The International Agreement for the Unification of the Anthropometric Measurements to Be Made on the Living Subject.* (20) This report, however, is extremely indefinite in many parts and is as much honored in the breach as in the observance by anthropologists generally.

Furthermore, these measurement standards were devised for the physical anthropologists who were concerned primarily with the comparison of bodily dimensions of the classes and races of mankind, who made no attempt to allow for differences in relative fatness of the body (fat measurements are not included in those techniques), and who were not in the least interested in the determination of the physical status of the measured. For the purposes of this Station and of anthropometrists in general who wish to study minute differences of physical status, a more rigid standardization of techniques is needed.

In the set-up of this study a careful investigation was made of techniques employed in the various institutions of this kind in this country as well as of the published accounts. The international Agreement (20, p. 10-33) and the methods pursued by Rudolf Martin (30) were studied most carefully and conferences were held with a number of anthropologists in this country who were interested in the problem of measurement for the estimation of physical condition. Certain modifications were made in the commonly used techniques, and the methods finally adopted are herewith presented. Where they differ from those commonly accepted, or where these present a technique which is not accurately indicated in the literature, the reasons for the same are given.

Before the techniques are discussed, the landmarks used and the instruments employed must first be listed and described. The landmarks and instruments indicated include only those employed in taking measurements which have been discussed in this study.

## LANDMARKS

The following landmarks are described:

1. Vertex: This is the highest point of the crown of the head when the individual is standing with the head in position for measurement. (See 4 below)

2. Tragion: This is the spot at the top of the small cartilaginous flap on the anterior border of the junction of the face and the ear just in front of the ear canal.

3. Orbitale: This is the point at the lowest border of the orbit of the eye. If one feels through the skin along the lower bony orbit, a small notch just below the center of the eye will be found. This marks the position of the orbitale.

4. Frankfort plane: This is a plane which runs through the tragion and orbitale of the two sides. In measurements of heights, this plane should be parallel to the ground.

5. Acromion: This is the outermost border of the acromion process of the scapula. In locating this point in those who are corpulent, the examiner will be aided by running his finger along the lower border of the spine of the scapulae out around to the outermost edge. The landmark should be located at the point of the skin directly above the outer border of the acromion.

6. Thelion: On prepubescent children and adult males this is the middle point of the nipple. On post-pubescent females, in whom the breast may have descended somewhat, this landmark is in the sagittal plane of the nipple, but the horizontal plane is at the upper border of the fourth chondro-sternal articulation.

7. Omphalion: This is the umbilicus.

8. Abdominal: This is the point midway between thelion and omphalion which is used for the so-called abdominal measurement of subcutaneous fat.

9. Xiphoid: The xiphoid cartilage, when present, is just below the lower end of the sternum and can be palpated in most males, though it is missing in many females. The tape is passed over about the middle part of the body of the xiphoid cartilage, or the place where the xiphoid would be if present.

10. Ilio-cristale: This is the widest part of the crests of the ilia

at the point tangent to the flat calipers when the planes of the blades of the calipers are parallel to the sagittal plane.

11. Trochanterion: The most lateral part of the greatest trochanter of the femur. If difficulty is found in palpating for this landmark, it will usually be found just below the level of the pubis. If it is still palpable with difficulty, ask the subject to press his legs together, thus relaxing the abductor muscles of the thighs and making the upper border of the trochanters more prominent.

12. Epicondyles of the elbow: This is the widest part of the humerus at the elbow. In locating this landmark, the elbow should be bent at approximately a right angle in order to remove the muscle masses of the extensors of the wrist from under the calipers. The muscles of the arm should be relaxed.

13. Epicondyles of the knee: This is the widest part of the femur at the knee. In locating this landmark, the knee should be bent from 45 degrees to 90 degrees in order that the hamstring muscles may not project out past the epicondyles.

14. Radiale: This is the notch just at the upper end of the radius, between the radius and the humerus. It is most easily found just below the level of the most prominent part of the olecranon process, and in the depression between the most prominent part of the ulna and the extensor muscles of the forearm.

The description of measurements below will give the level and place of other measurements which are not located over definite anatomical landmarks, but which are given in relationship to landmarks on other parts of the body.

## INSTRUMENTS

The following instruments are used:

1. Broca plane: This is a vertical board about 18 inches wide, fixed at right angles to a horizontal board at the bottom and extending upward from the horizontal board at least 2 meters. To this plane is attached a measuring scale. At the Iowa Child Welfare Research Station a paper measuring scale is used. This scale consists of a strip of the best type of inextensible and unshrinkable heavy paper 2 meters long and 12½ centimeters wide, with metric divisions on the right edge of the scale in millimeters and English divisions on the left edge of the paper in inches and tenths of inches. Where the wall is an absolutely smooth plane without a baseboard and at right angles to the floor, this may be used as the

plane. A scale can be conveniently made by countersinking two-meter sticks into the wall or plane. If English equivalents are desired, yard sticks may be sunk into the wall beside the meter sticks.

This type of plane has a number of advantages over the fixed rod or stadiometer in that it is more solid and gives more points for fixation of the body. It presents a still further advantage over the anthropometer, which offers difficulty both in standardizing the standing position and in keeping the instrument absolutely vertical.

2. Square: The square consists of two pieces of seasoned wood (preferably walnut, buttonwood, or plywood) 18 centimeters by 13 centimeters, joined at right angles. Within the angle on the median line of the two planes is a narrow strip 5 millimeters thick, in which is cut an opening through which the hand may be inserted. The size of the square may vary a little from the above dimensions.

3. Measuring board for infants: Figure 4 shows a measuring scale for determining the reclining length (crown-heel) and the reclining sitting height (crown-rump) for infants. It was designed by Professor Bird T. Baldwin and made in the manual training shop of the University. The scale is 1 meter in length with an additional margin of 4.5 centimeters at one end. The width is 20.5 centimeters, with a standardized buttonwood millimeter scale on one side and an inch scale on the other. The vertical plane (a) for

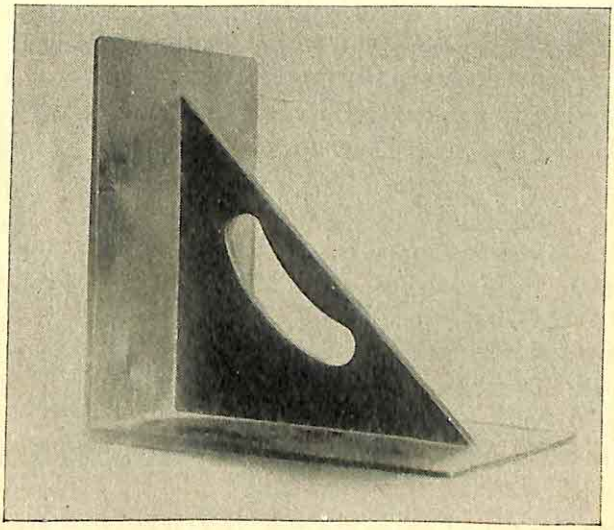

Figure 3. The Square

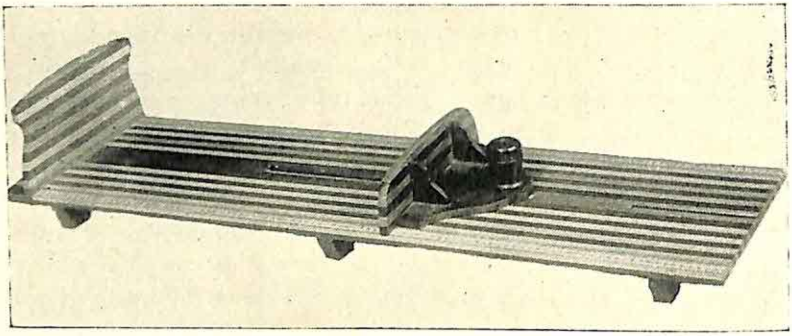

Figure 4. Measuring Board for Infants

the top of the head to rest against is 15 centimeters at its greatest height, and the sliding vertical plane (b) is attached to a brass rod (c) which moves freely in a brass groove in such a manner that the reading may be taken from either scale. The board is made of inlaid walnut and buttonwood or plywood, and the standards on which it rests when in contact with the table are covered with heavy felt. The scale is accurate and portable.

4. Bench: This is used for the measurement of sitting height. It must be made of thoroughly seasoned wood to prevent its warping and changing height from time to time. Several benches will need to be prepared for different sizes of children. For the smallest children, the bench should be 30 centimeters high by 30 centimeters square. For somewhat larger children a bench 40 centimeters high by 40 centimeters square should be used, and for adults a 50 centimeter bench is desirable, although the 40 centimeter bench may be used in the majority of cases. (Figure 5)

5. Large sliding flat calipers: This is made of a hollow rod 70 centimeters long, 2.2 centimeters broad, and .8 centimeter thick made of well nickeled and welded brass strips and of aluminum branches 26 centimeters long (in the free) and 3.5 centimeters broad. The Hrdlička compass made in Washington, D. C. for the Station has been tested by the Bureau of Standards. This compass has been made also by Collin in Paris. It may be secured from Dr. Aleš Hrdlička, Washington, D. C. or from various instrument houses.

This metal caliper is light, very serviceable, durable, and accurate. It is, however, quite expensive. A number of wooden calipers are available, but these are subject to more inaccuracies unless the measurements are taken much more carefully, as the wooden arm

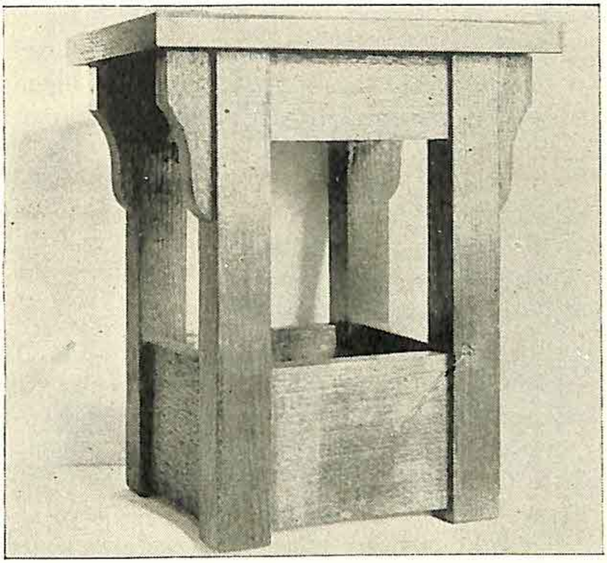

Figure 5. Bench

springs more freely than does the metal arm, and these instruments are in some cases apt to warp. If, because of the expense, the wooden caliper must be used, it should be ordered subject to approval after being tested and should be checked from time to time for accuracy by measuring some solid substance of known width.

6. Tapes: Standard millimeter steel tapes should be used. The linen tapes sometimes used are entirely satisfactory as long as they

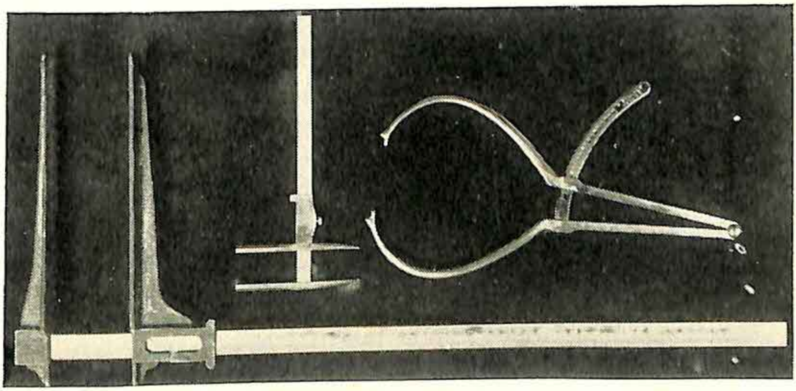

Figure 6. This illustration shows the large sliding calipers, a pair of small sliding calipers for taking face measurements, and a pair of curved calipers for measuring the diameter of the head.

do not shrink, and they have the advantage of not being cold to the skin. If these are used, they should be tested daily throughout the measurement time for shrinkage. Experience with linen tapes in this Station has been unsatisfactory, as shrinkage has been found to be very common.

Some tapes are made with a spring attachment at one end for the purpose of standardizing the pull. These are not recommended at this Station. Reasons for this will be given under the discussion of techniques of measurement (p. 118).

7. Calipers for the measurement of skin and subcutaneous tissue: Calipers for this purpose were devised by the American Child Health Association and are now available from the American Public Health Association, 50 West 50th Street, New York City. It is exceedingly important that the springs of these calipers be standardized. The calipers as sent out by the manufacturer vary considerably in tension and no absolute standards have as yet been published. This Station has perfected its own standards for these calipers, and they may be applied as follows:

The fixed arm of the calipers is clamped in a small vise in such a way that the arms are horizontal. A plumb bob weighing 327 grams is hung by a thread over the second groove from the end of the free arm. This is oscillated up and down and permitted to come to a free rest several times in succession. The indicator should read 17 on the scale. A second weight of 257 grams is added to the first weight and the free arm is again oscillated. The indicator should read approximately 35. If the reading differs significantly from these figures, the spring should be adjusted and the test repeated until approximately these standards are obtained.

This standard is difficult of application since it depends upon the weight of two plumb bobs, which were purchased locally. However, the Iowa Child Welfare Research Station will be glad to test the springs of the calipers for anyone desiring that service.

8. Scales: Almost any of the standard makes of beam scales are satisfactory. If new scales are being purchased, it is recommended that double or triple beam scales be secured, the latter being the most desirable. These obviate the necessity for movable weights which are not infrequently lost. These scales should be checked against the standard weights when purchased, and, if purchased from the manufacturer with a guarantee of accuracy, will almost in-

variably be found entirely accurate. Barring accidents, there is little reason to expect scales of the beam type to vary.

Spring scales differ very much in their dependability. Quite satisfactory spring scales can be purchased, however, which are accurate to within about half a pound. Some of these can be had with a guarantee from the manufacturer. This Station has made use of two platform spring scales which have not varied more than half a pound in three years. If this type of scale is made use of, however, it should be checked against standard weights before every general measuring period, or at least every three months. The platform beam scale is, of course, much more satisfactory.

9. Wet spirometer: Spring spirometers and others of the so-called "dry" spirometers have not been found accurate enough for scientific work. There are several varieties of wet spirometers, and these differ in their accuracy. The most satisfactory type of wet spirometer consists of two cylindrical tanks open at one end and fitted within each other so that the closed ends form the top and bottom of the instrument. The tanks are made of galvanized tin. The outer one is 31 centimeters high and has a diameter of 19.5 centimeters; the inner tank is 29 centimeters high and has a diameter of 18 centimeters. The outer tank is half filled with water and has in the center a 1 inch metal tube that projects up into the inner tank. The base of the instrument is hollow and has three openings. On the left-hand side is a pipe with two openings. To one of these is attached a rubber tube fitted with detachable wood or glass mouth-pieces, through which the subject blows. The other opening is fitted with a rubber cork for expelling the air after the test.

The outer tank is fixed between two stationary pipes the same height as the tank. Into each of these fit brass tubes 27 centimeters high above the stationary tubes. The brass tube on the left is graduated in cubic inches and cubic deciliters and can be revolved so that the measurement may be read by either scale. A cross bar connects the two brass tubes. On each side of the bar is a small pulley over which passes a cord attached at one end to a weight of .3 kilogram which hangs within the brass tube, and at the other end to a small hook which is attached to a metal ring on the outer edge of the top of the inner tank. Attached to the ring on the left-hand side is an indicator by means of which measurements on the brass tube are read. On the right-hand side of the outer tank is a hook on which the rubber tube is hung when the instrument is not in use.

The wet spirometer operates on the displacement principle. When the subject blows through the rubber tube, the air enters the hollow base and passes up through the pipe in the center of the outer tank and causes the inner tank to rise.

The temperature of the water inside the wet spirometer is very important. Since the expired air, which is at blood temperature and saturated with water vapor, passes up through the pipe surrounded by water, if this water is cool, the volume of the air contracts and some of the water vapor is precipitated out. This may reduce the volume of the air as much as 15 per cent. If the water is too warm, on the other hand, additional water vapor may be absorbed from the water into the air and the air will expand, giving a spuriously large volume. Tables for the correction of spirometer readings for varying temperatures have been prepared (25), but the more satisfactory procedure is to keep the temperature of the water the same as the room temperature. This will vary from 25 degrees to 27 degrees Centigrade. The standards which have been prepared at this Station and elsewhere are in terms of water at room temperature, so that correction tables need not be used.

## TECHNIQUES OF MEASUREMENT

1. Weight: Before beginning measurement at any given period, see that the scales are balanced. Request the subject to stand in the center of the platform of the scales. The weight should be taken nude when possible. If the subject is weighed in some garment, the weight of this should be subtracted from the weight shown by the scales. In any case, coats, shoes, and overclothing should be removed.

2. Standing height: The subject stands straight with heels together and heels, back of hips, upper part of back, and back of head against the wall or Broca plane to which the measuring scale is attached. The arms are permitted to hang at the side in a natural position and the head is held with the Frankfort plane horizontal. The square is placed on the top of the head, care being taken that it is parallel to the floor. Press firmly enough upon the vertex to press down the hair, then read the height on the scale. During the measurement the subject should be requested to "stand as tall as he can," care being taken to see that he does not raise his heels from the floor. (Figure 8)

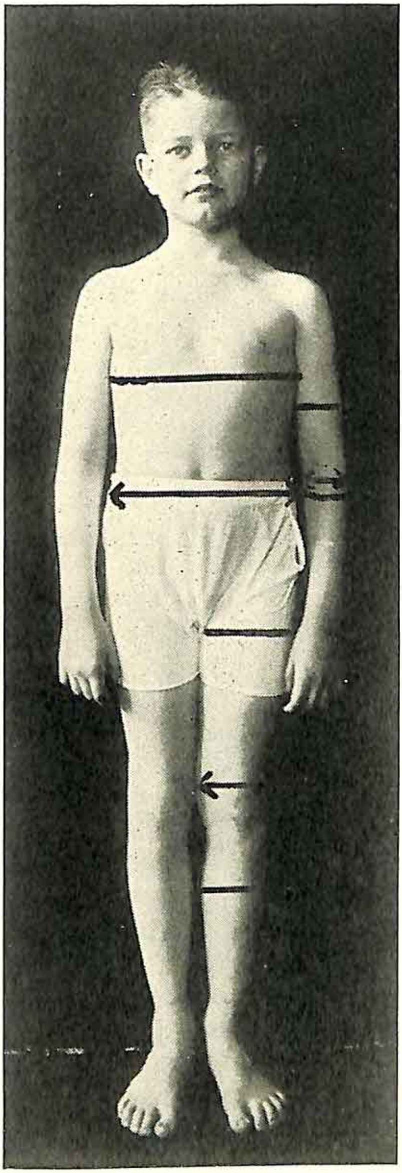

Figure 7. Locations of Measurements for Prediction of Normal Weight and of Limb Girths

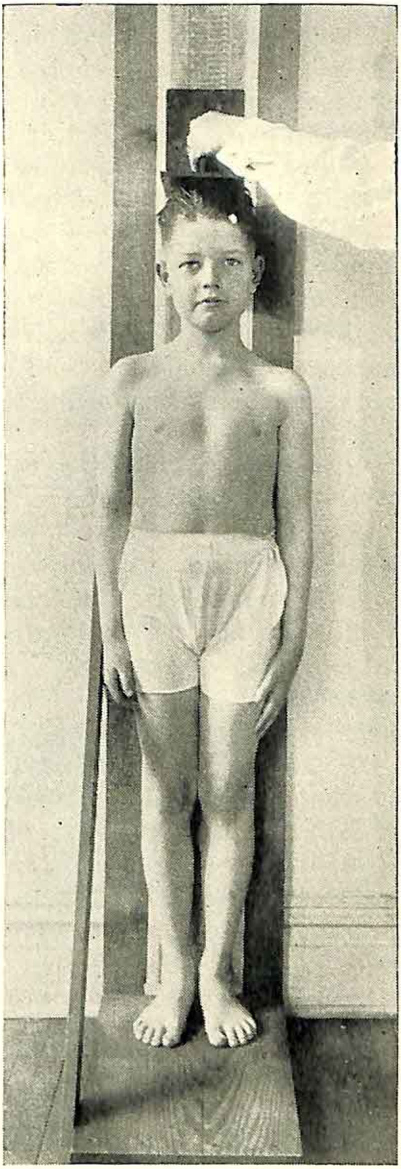

Figure 8. Measurement of Standing Height

3. Sitting height: The bench is placed in front of the scale, selecting the bench of the proper height according to the stature of the subject. The subject then is seated on the bench leaning forward with his hips pushed firmly back against the wall. He should then cross his feet in front of the bench and straighten up, sitting as tall as possible, without tension of his thigh muscles. The hips, back of the shoulders, and back of the head should be in the same position as when measuring standing height. (The provision which suggests that his feet be crossed is for the purpose of releasing as much as possible the tension of the gluteal muscles and to permit the subject's weight to settle upon the ischia rather than upon tensed muscles.) The height is measured in the same way as described under standing height, and the height of the stool is then subtracted from this record.

4. Shoulder width: The observer stands behind the subject, who is instructed to stand erect with his arms straight and hands held closely against his thighs. Using the flat calipers, the observer measures the distance between the two acromia.

5. Measurements of the chest: In measurements of the chest, the subject should stand erect but not rigidly so. The head should be held erect, not looking downward. The arms are released and held slightly away from the body in order to permit the passing of the instrument beneath the arms.

In measuring chest depth the observer stands on the right side of the subject. The measurement is taken with the large flat calipers, with the movable arm over the xiphoid cartilage. The fixed arm is over the back, beneath the scapulae with the rod passing under the right arm. The rod should be perpendicular to the spine. The instrument should be held very lightly against the skin, indenting the skin no more than necessary. The movable arm of the calipers should follow the excursion of the chest over three or four respirations and the midpoint of normal respiration recorded.

Chest width is also taken with the large flat calipers. The observer stands in front of the subject and applies the calipers to the chest in such a way that the rod lies directly over the xiphoid cartilage, with the arms of the calipers perpendicular to the spine and the ends of the arms in front of the latissimus dorsi muscles (the large muscles just behind the axillae). The fixed arm of the calipers is at the right side of the chest and the movable arm at the left side. The pressure should be as light as possible, and the calipers should follow the excursion of the chest during normal expiration and inspiration, and the midpoint recorded.

In measuring circumference of the chest the observer stands in front of the subject and passes the tape around his chest so that it crosses the front of the chest at the level of the xiphoid cartilage, the plane of the tape being at right angles to the spine. This is normally almost parallel to the floor. The position of the tape in front will be from 2 to 3 centimeters below the large chest muscles in the male and very close to the base of the mammary gland in the female. The tape should rest against the perimeter of the chest only tightly enough to prevent its slipping. (Figure 9)

In taking chest measurements we have stressed the fact that instruments should rest very lightly against the chest. The purpose is to measure the external dimensions of the chest, not to compensate for varying degrees of thickness of the skin or fat. These compensations are made by corrections derived from the fat measurements. If the spring tape is used, the experience has been that it causes the tape to press inward on the skin in varying amounts, depending upon the softness of the underlying tissue. Two individuals with the same thickness of subcutaneous fat around the chest may have a quite different consistency of that fat. In one

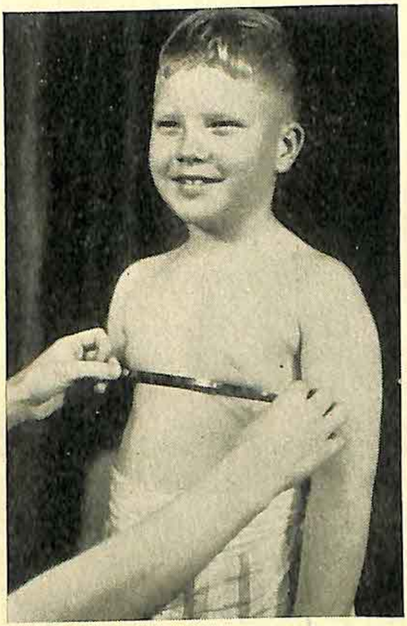

Figure 9. Measurement of Chest Girth

case the spring tape may press in with half a centimeter indentation, and in another a full centimeter. This would make a difference of 3 centimeters in the circumference.

6. Bi-iliac width: The measurement is of the maximum external diameter of the outermost points of the crests of the ilia (ilio-cristale). In taking this measurement, the observer stands in front of the subject with the face of the blades of the calipers held in such a way that the outer edge of the bone is about in the middle of the blade. Usually the arms of the calipers are directed from before backward and downward. In taking this measurement, the observer uses the maximum of pressure that can be exerted without pain to the subject. (Figure 10)

7. Bi-trochanteric width: In taking this measurement the observer stands in front of the subject, who is instructed to stand with his feet together from heel to toe. The blades of the flat calipers are placed over the trochanters, just touching the skin, without pressure. (This measurement is used only for the purpose of com-

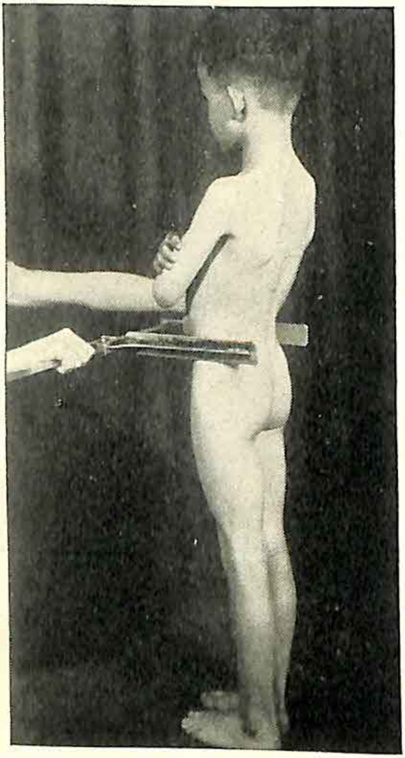

Figure 10. Measurement of Bi-Iliac Width

parison with the bi-iliac measurement to obtain a rough measurement of the fat over the trochanters. It should not be confused with the other standard bi-trochanteric measurement in which pressure is used for a measurement of the width of the hips.)

8. Elbow width: The subject raises the left arm forward to the level of the shoulder and flexes the forearm upward to a right angle. The blades of the flat calipers are applied over the epicondyles of the elbow with the blades bisecting the angle of the elbow and in the plane of the forearm and upper arm. As much pressure is used as can be borne by the subject without pain. (Figure 11)

9. Width of knee: The subject places the left foot on a stool in order to bend the knee to something near a right angle and to relax the muscles of the leg. The observer stands in front of the subject and applies the blades of the flat calipers to the epicondyles of the femur so that the blades bisect the angle of the leg and are parallel to the plane formed by it. Maximum pressure is used. (Figure 12)

10. Girths of limbs: In measuring the girths of the limbs the steel tape is used, in every case applied as lightly as possible to avoid indenting the skin.

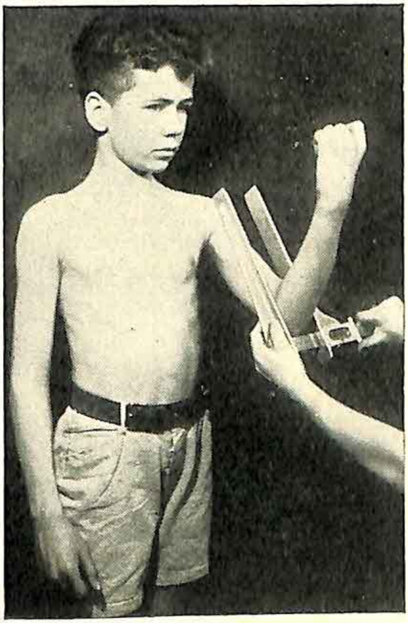

Figure 11. Measurement of Elbow Width

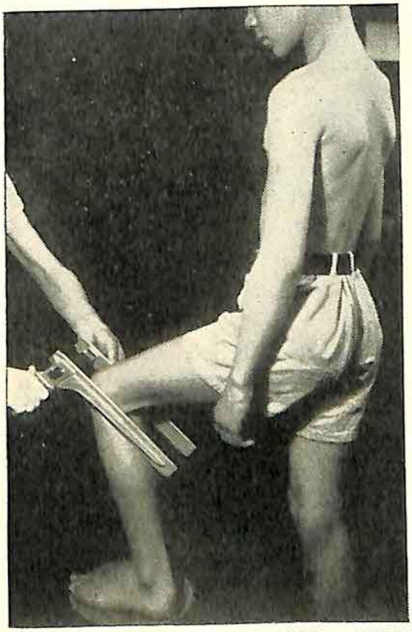

Figure 12. Measurement of Knee Width

In measuring the girth of the upper arm the left arm is held downward and straight and very slightly separated from the body. The tape is passed around the arm approximately halfway between the acromion and radiale at the largest part of the arm. If in doubt as to the place, the subject may be requested to flex the elbow, noting the point of greatest bulge over the biceps. The tape is then placed at this point after the arm is again straightened. The plane of the tape is at right angles to the line of the humerus. (Figure 13)

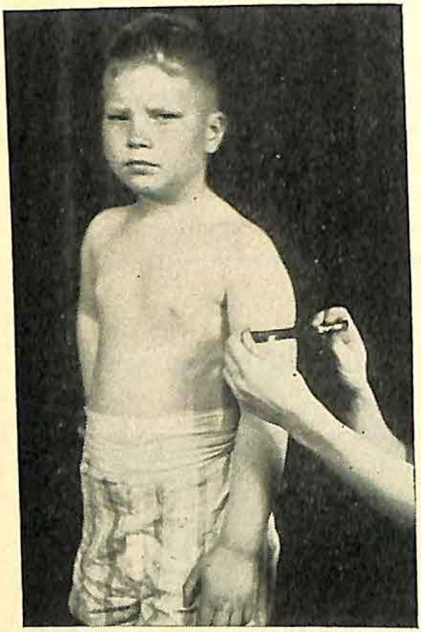

Figure 13. Measurement of Girth of Upper Arm

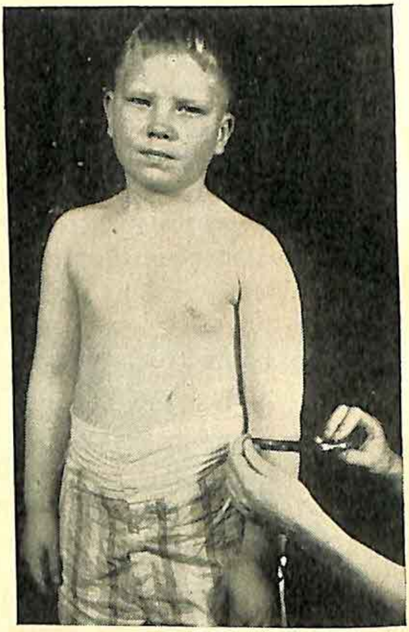

Figure 14. Measurement of Girth of Forearm

The tape is placed around the greatest diameter of the forearm muscles with the hand opened when the girth of the forearm is measured. This is just about at the level of the radiale. While the measurement is taken, the elbow must be straight. (Figure 14)

In thigh girth the subject stands with his feet about 1 foot apart (less in small children), with the weight evenly distributed on both legs. The tape is passed around the thigh at right angles to its long axis, just below the gluteal fold behind. (Figure 15)

Girth of the calf is measured at the largest point of the calf with the weight evenly distributed on both feet. (Figure 16)

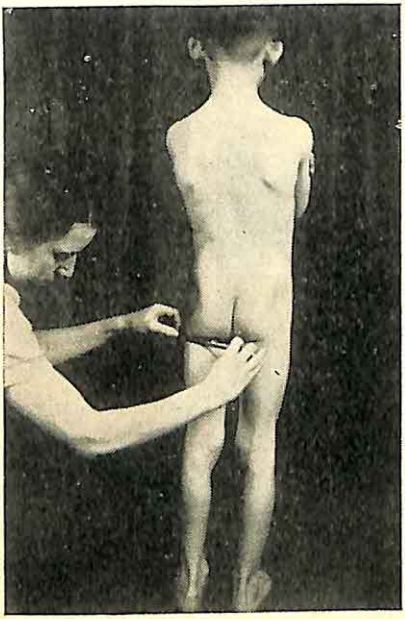

Figure 15. Measurement of Girth of Thigh

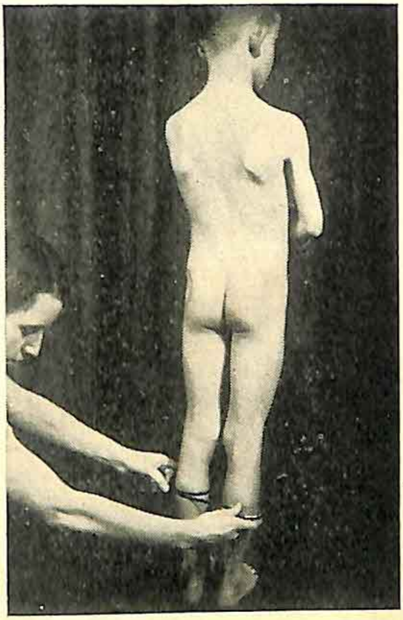

Figure 16. Measurement of Girth of Calf

It is the custom to take all limb measurements on the left side.

11. Measurements of skin and subcutaneous tissue: The technique for this measurement employed at the Iowa Child Welfare Research Station differs in some respects from that published elsewhere (17, p. 108-110). The observer grasps a double layer of skin and subcutaneous tissue with the thumb and forefinger of the left hand, with the thumb and forefinger pointing toward each other. (See Figure 17) This fold of skin should be large enough to get a complete double layer, but not so large as to get so much skin and fat as to cause too great an amount of tension beyond the finger tips. The fold of skin and fat is held somewhat loosely while the calipers are applied in such a way as to be about 2 millimeters above the ends of the thumb and fingers. The spring is then released and the calipers held down against the fold of skin to prevent its slipping away, and the measurement is recorded. (See Figure 17)

The fat measurement on arm front is taken over the center of the biceps muscle of the left arm with the arm straight. The blades of the calipers are parallel to the long axis of the arm and are applied

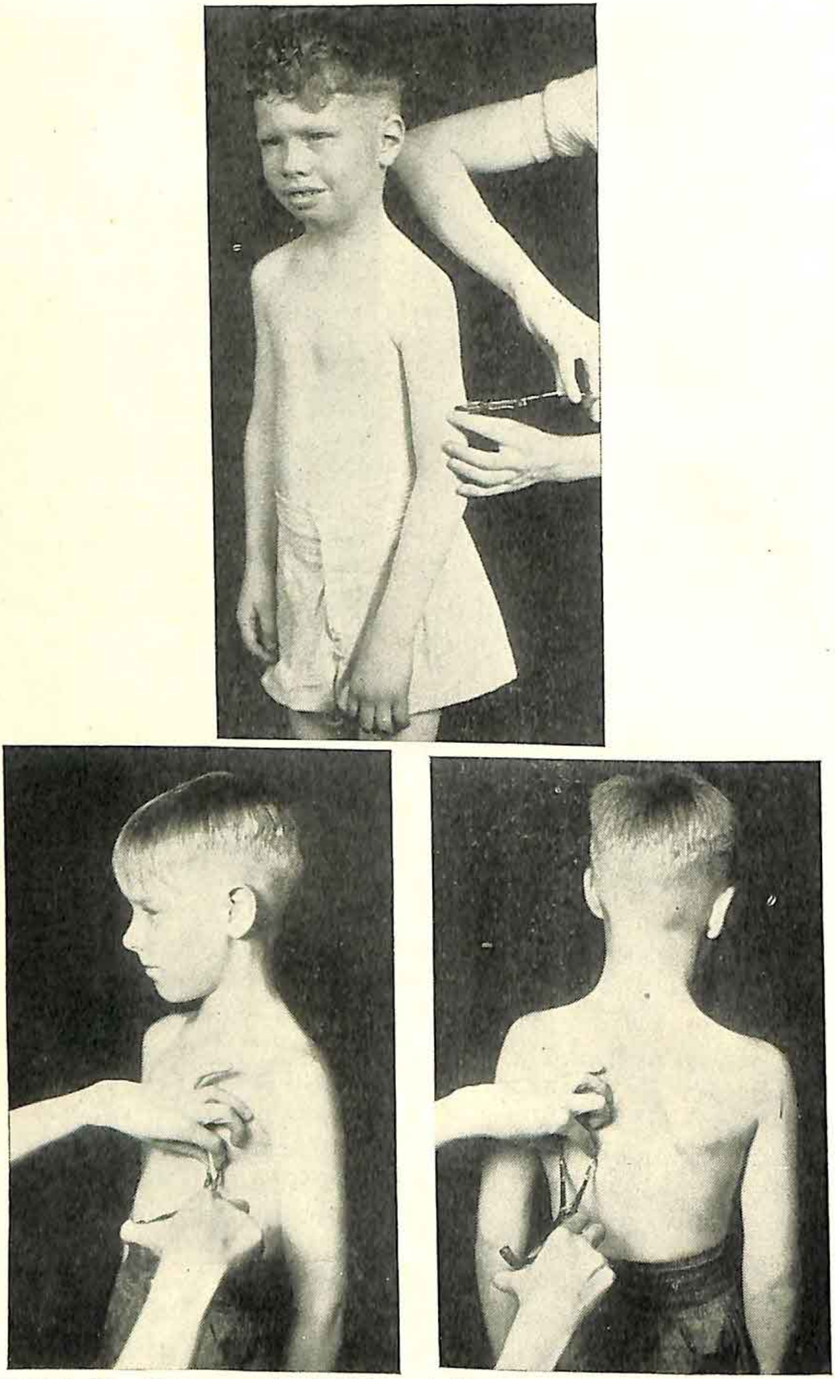

Figure 17. Measurement of Skin and Subcutaneous Tissue (3 pictures)

midway between the acromion and the radiale. In obtaining such a measurement at the back of the arm the calipers are applied midway between acromion and radiale over the midpoint of the triceps muscle with the arm straight and downward and the blades parallel to the long axis of the arm.

In taking the fat measurement of chest front the calipers are applied to the skin at the level of the xiphoid cartilage and approximately halfway between the sagittal planes passing through the sternum and tangent to the side of the chest. The blades of the calipers are vertical. In the chest back measurement the calipers are placed at the level of the plane of the xiphoid cartilage over the most prominent part of the back muscles. The blades of the calipers are vertical.

In the abdominal fat measurement the blades of the calipers are placed over the front of the abdomen, midway between the thelion and omphalion, just over the border of the rib cartilages. The blades of the calipers are parallel to the line from thelion to omphalion.

For the supra-iliac measurement the calipers are applied just above the crest of the left ilium in a line vertically downward from the left armpit. The blades of the calipers are vertical.

In all of the above fat measurements, the measurement is commonly taken on the left side.

The fat measurement, hip difference, is secured by subtracting the bi-iliac hip measurement, corrected for fat, from the bi-trochanteric measurement taken without pressure.

Breathing capacity: Using the wet spirometer, with the water temperature from 25 degrees to 27 degrees Centigrade, the subject is instructed to take as deep a breath as possible and to exhale it as completely as possible through the tube into the spirometer. The subject takes at least three trials and continues as long as the record is increasing.

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